

Manovre e stabilità

Laurea Ingegneria Aerospaziale, II anno, 6CFU

Docente

Agostino De Marco

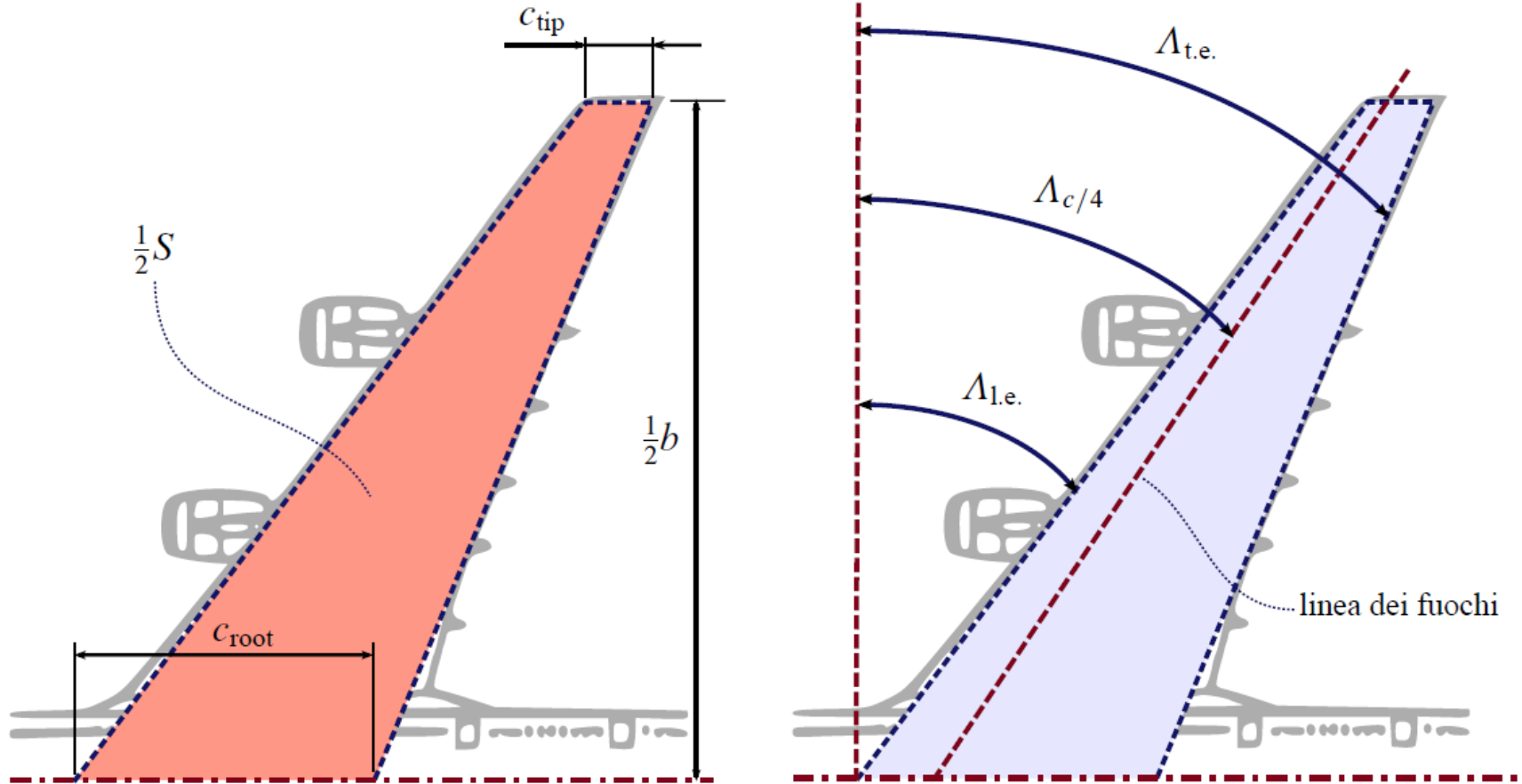
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Ricevimento: lunedì, 15:00 — 17:00; mercoledì, 11:00 — 13:00 (su appuntamento)

Ali finite



Ali finite, geometria



(a) Semiarea della forma in pianta, semiapertura alare, corde di radice e di estremità. (b) angoli di freccia del bordo d'attacco, della linea dei fuochi e del bordo d'uscita.

Figura 4.1 Definizioni di superficie alare ed angoli di freccia di un'ala dritta.

Ali finite, definizioni

$$\mathcal{R} = b^2/S$$

$$\bar{c} = \frac{S}{b} = \frac{1}{b} \int_{-\frac{b}{2}}^{+\frac{b}{2}} c(Y) dY$$

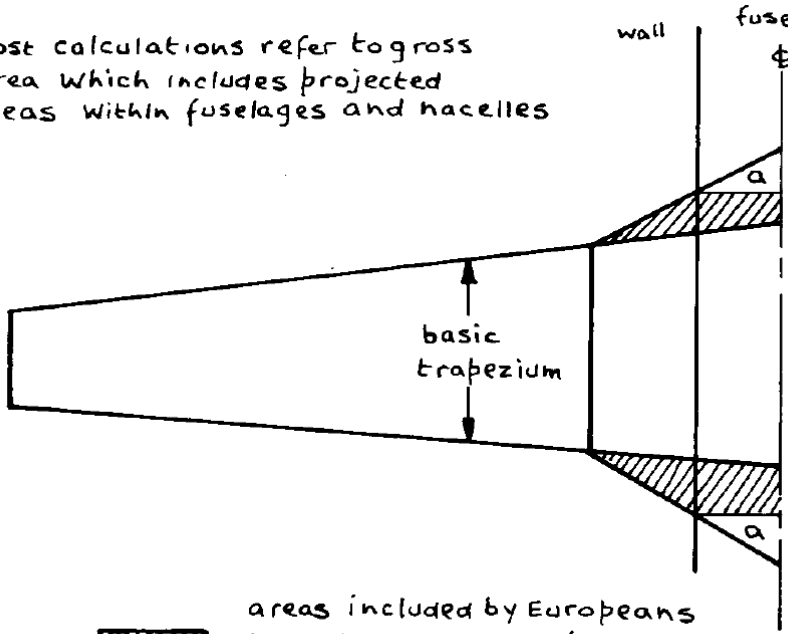
$$\mathcal{R} = b/\bar{c}$$

Corda media *geometrica*

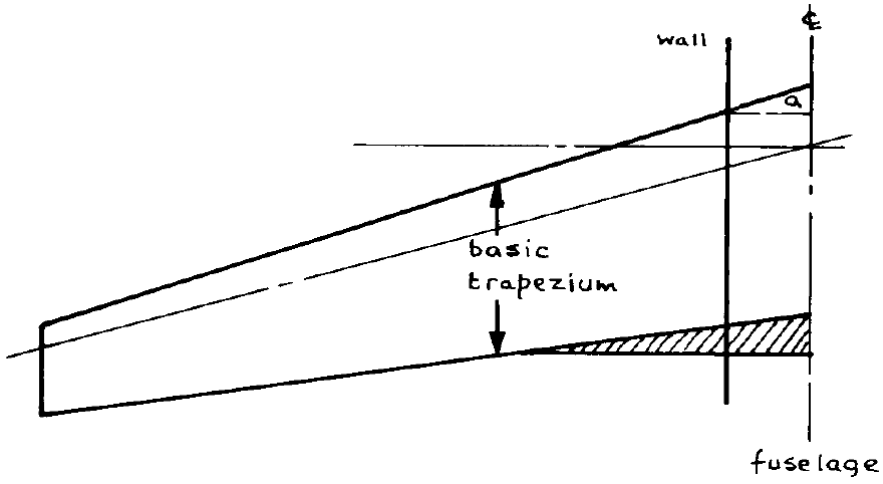
Per ali a bordi dritti:

$$\bar{c} = \frac{1}{2} (c_{\text{root}} + c_{\text{tip}})$$

Most calculations refer to gross area which includes projected areas within fuselages and nacelles



areas included by Europeans but often omitted from aspect ratio calculations by Americans



Ali finite, definizioni

Allungamento
alare

Corda media *geometrica* o
standard mean chord

$$\mathcal{R} = b^2/S \qquad \bar{c} = \frac{S}{b} = \frac{1}{b} \int_{-\frac{b}{2}}^{+\frac{b}{2}} c(Y) dY \qquad \mathcal{R} = b/\bar{c}$$

Tabella 4.1 Valori tipici dell'allungamento alare di velivoli appartenenti a diverse categorie.

<i>Tipo di velivolo</i>	<i>Esempi</i>	\mathcal{R}
Bimotore ad elica (brave tratta)	ATR-42/72	12
Con 2-4 motori, ad elica (media tratta)	G-222, C-130	9 – 9,5
Bimotore (getto-turbofan)	DC-9, B-737	8,25 – 8,85
Trimotore (turbofan)	DC-10, MD-11, B-727	7,6
Quadrimotore (getto-turbofan)	B-747, B-787, A-380	6,7 – 7,3
Caccia subsonico	MB-326/339	4 – 5,3
Caccia e caccia-bombardiere supersonico	F-104, F-15	1,9 – 2,5
Da trasporto supersonico	Concorde	1,8 – 2
Aliante	ASW-24, Grob G103	20 – 30

Ali finite, definizioni

$$\lambda = c_t / c_r \quad \text{Rapporto di rastremazione}$$

Tabella 4.2 Valori tipici dell'angolo di freccia di velivoli appartenenti a diverse categorie.

<i>Tipo di velivolo</i>	$\Lambda_{c/4}$
Aerei militari e civili (basso subsonico)	$0^\circ - 20^\circ$
Aerei militari e civili (alto subsonico)	$25^\circ - 37^\circ$
Velivoli supersonici con ali a delta	$40^\circ - 80^\circ$

Ali finite, definizioni

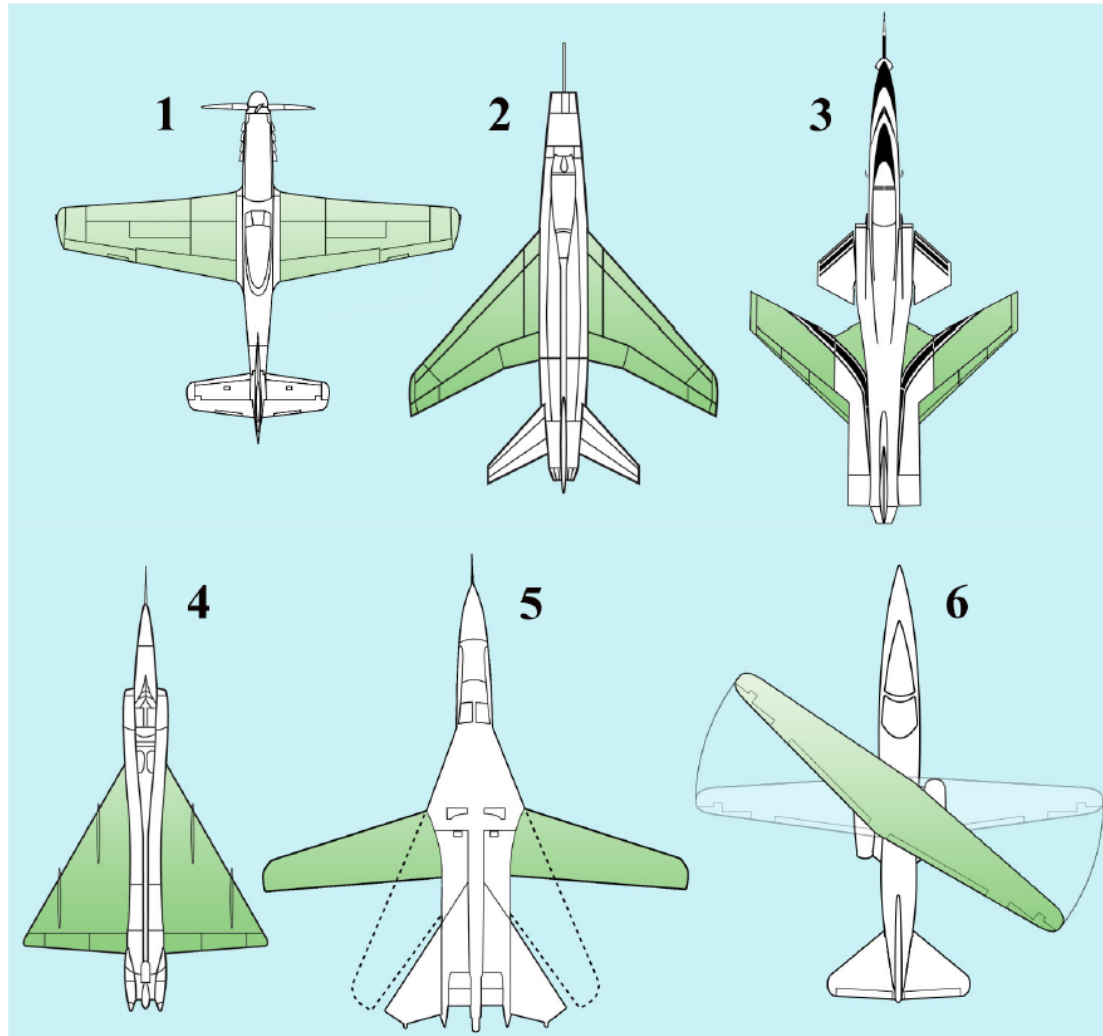


Figura 4.23 Alcuni velivoli dotati di ala con diversi angoli di freccia. 1) P-51, freccia nulla; 2) XY, $\Delta_{l.e.}$ di circa 45° ; 3) Grunman X29, a freccia negativa; 4) Dassault Mirage, ala a delta; 5) F111, a freccia variabile; 6) XY, velivolo sperimentale detto ad “ala obliqua” (*Oblique Wing*).

Ali finite

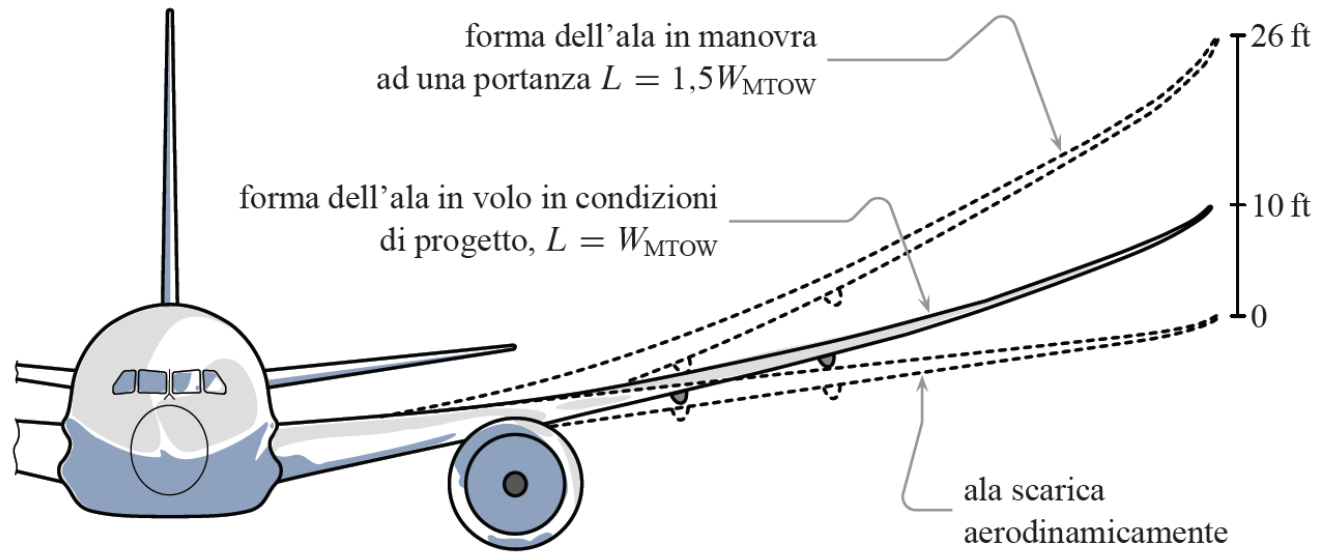


Figura 4.3 Variabilità del diedro alare del velivolo Boeing 787 in diverse condizioni di volo.

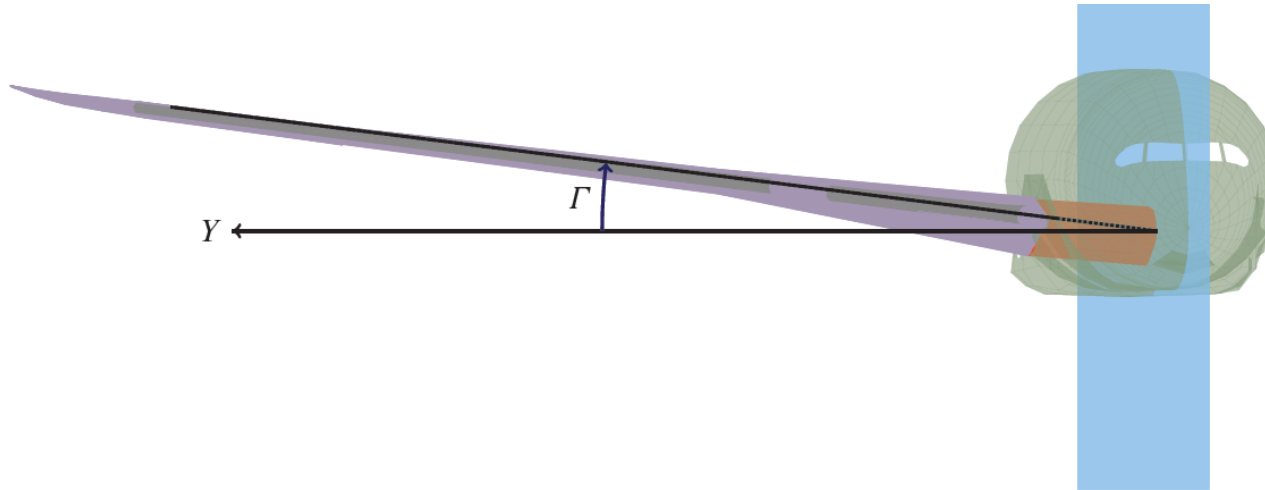


Figura 4.2 Angolo diedro dell'ala, Γ .

Ali finite

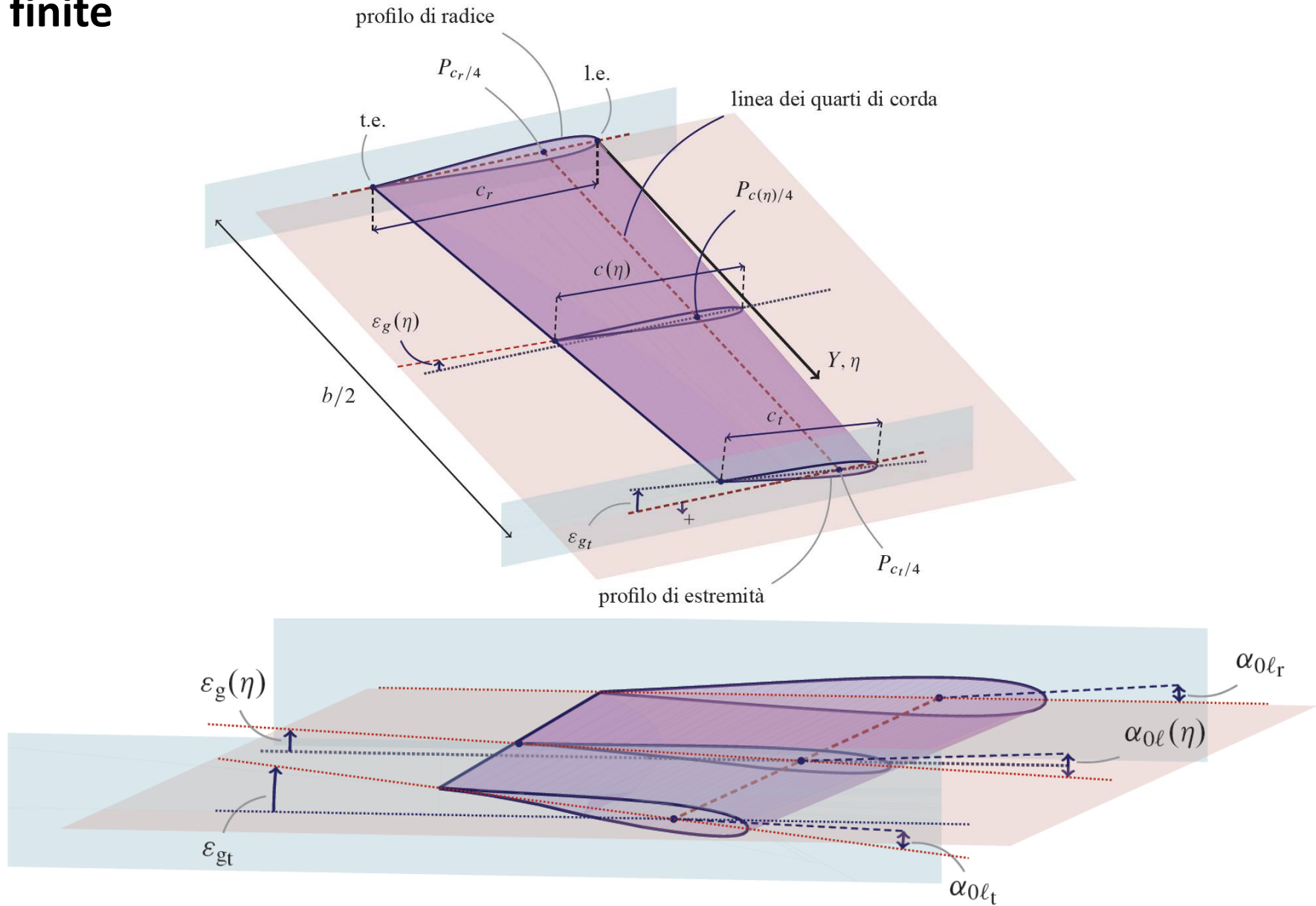


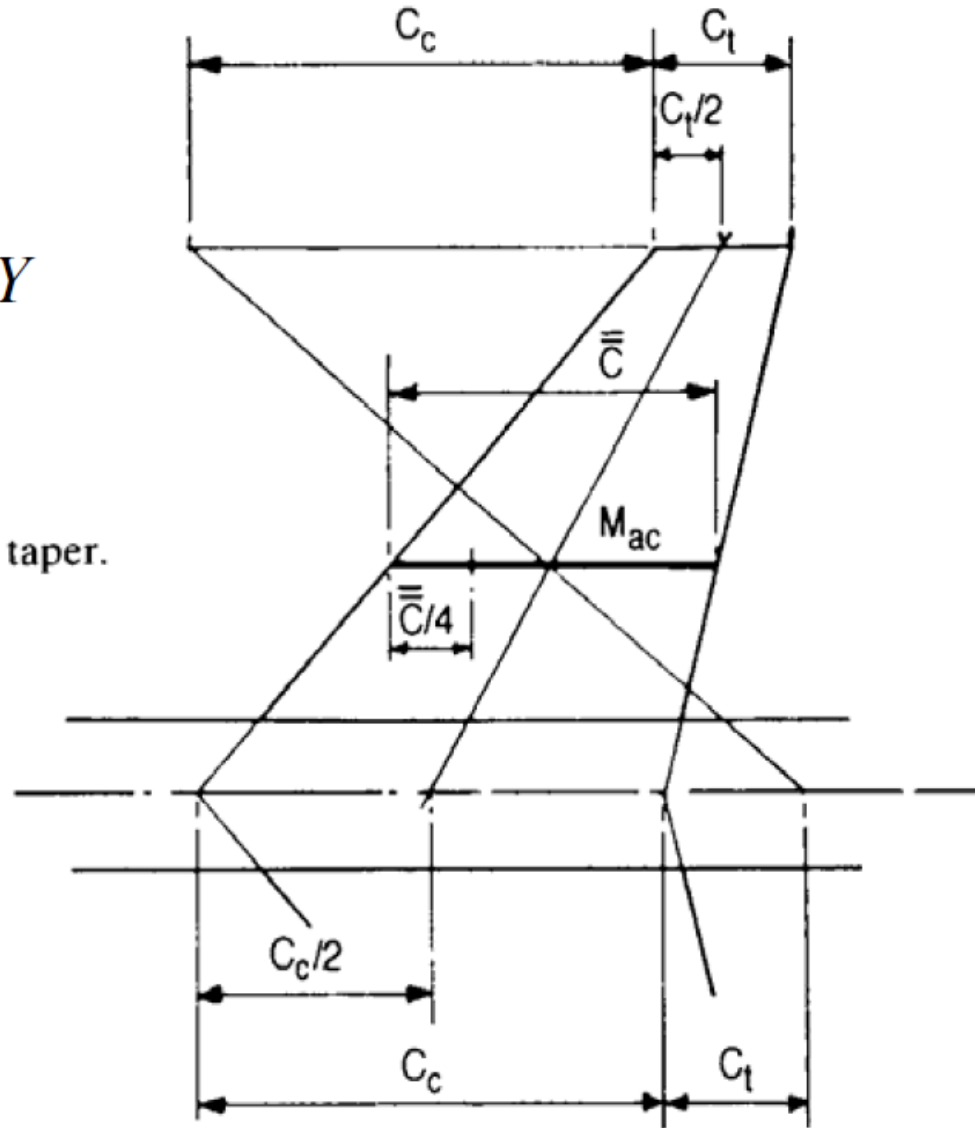
Figura 4.4 Un'ala dritta ed i diversi calettamenti delle corde e delle rette di portanza nulla.

Ali finite, corda media aerodinamica (c.m.a)

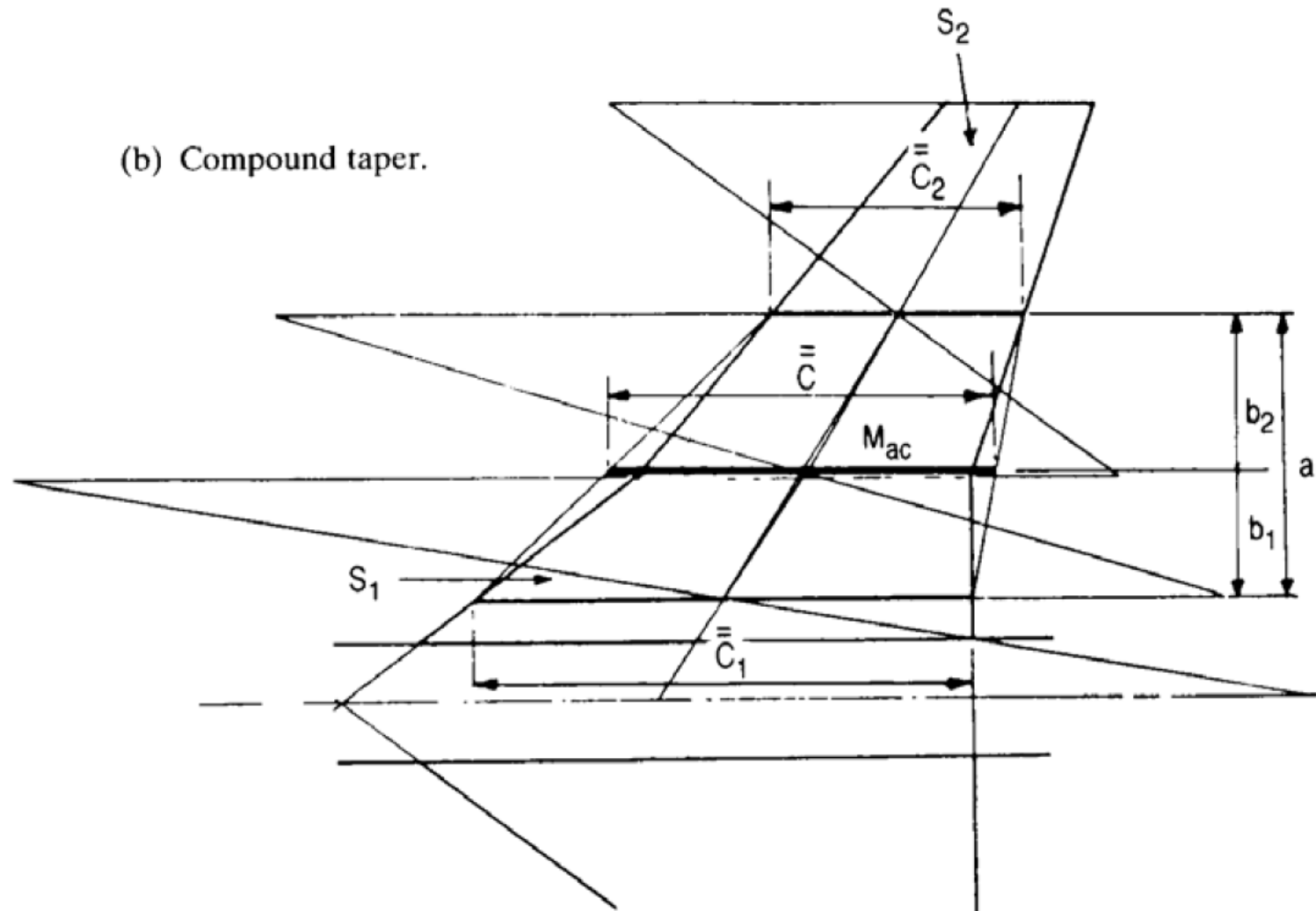
Corda media
aerodinamica

$$\bar{c} = \frac{1}{S} \int_{-\frac{b}{2}}^{+\frac{b}{2}} c^2(Y) dY$$

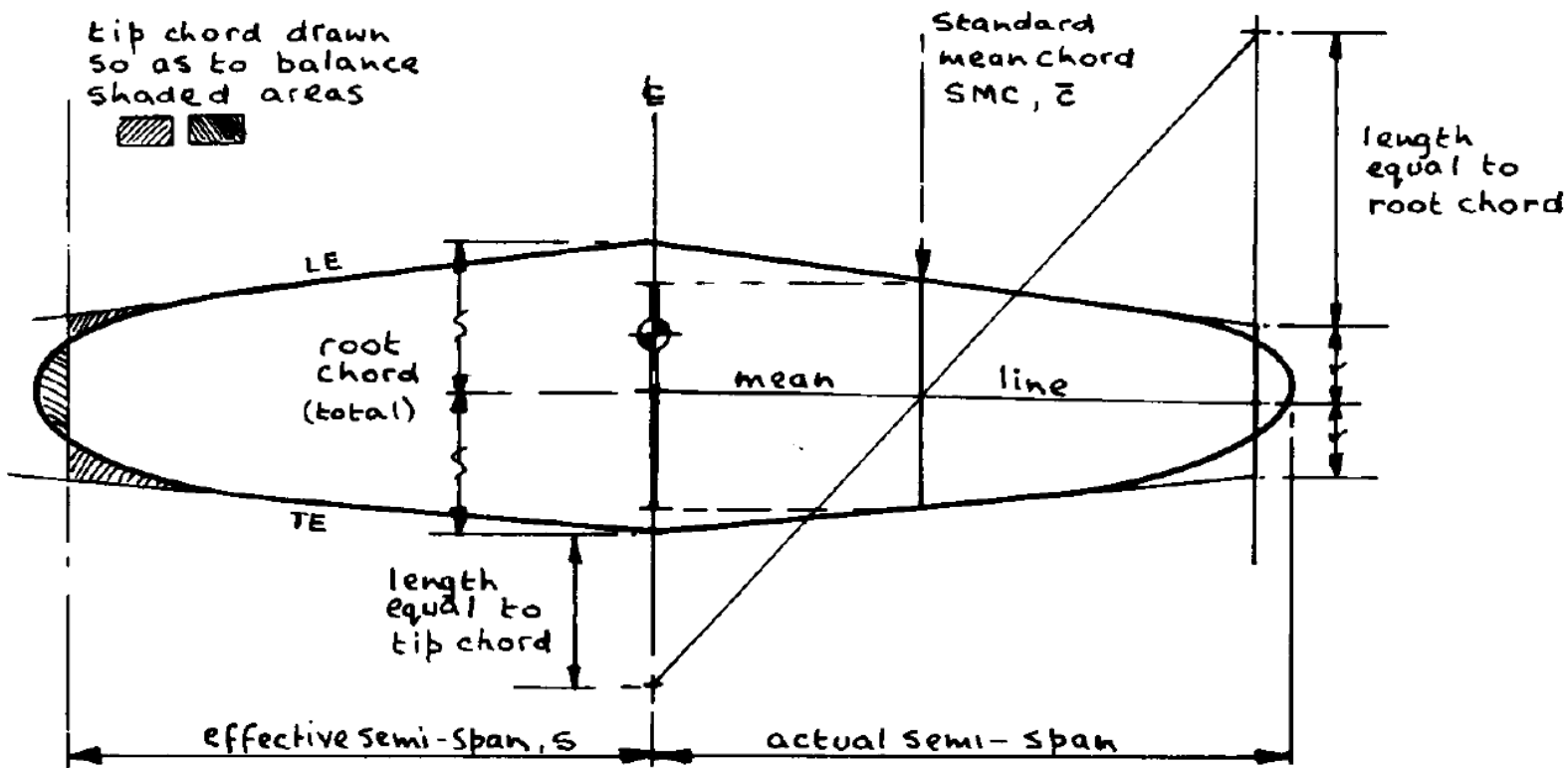
(a) Straight taper.



Ali finite, corda media aerodinamica (c.m.a.)



Ali finite, corda media aerodinamica (c.m.a.)



⊙ location of centre of gravity at $1/4$ SMC. we now have a starting point for drawing a sensible aeroplane

Fig. 2.5 The way to deal with planform and construction of standard mean chord for area and aspect ratio calculations (see eq (2-2)).

Ali finite, genesi della portanza

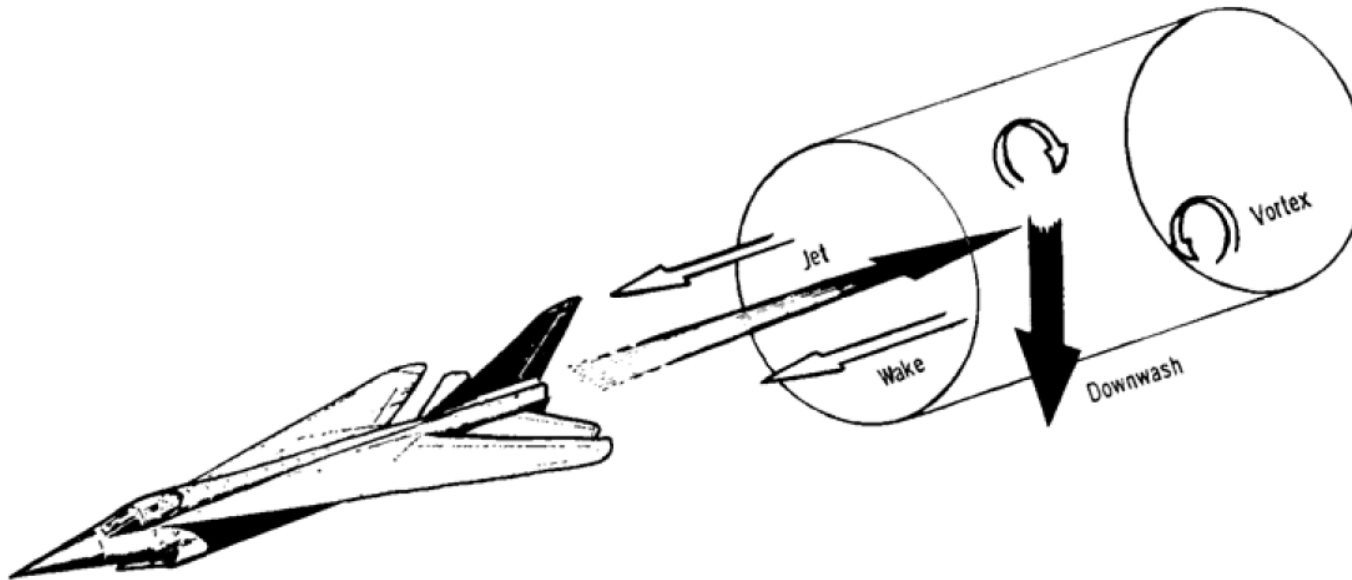
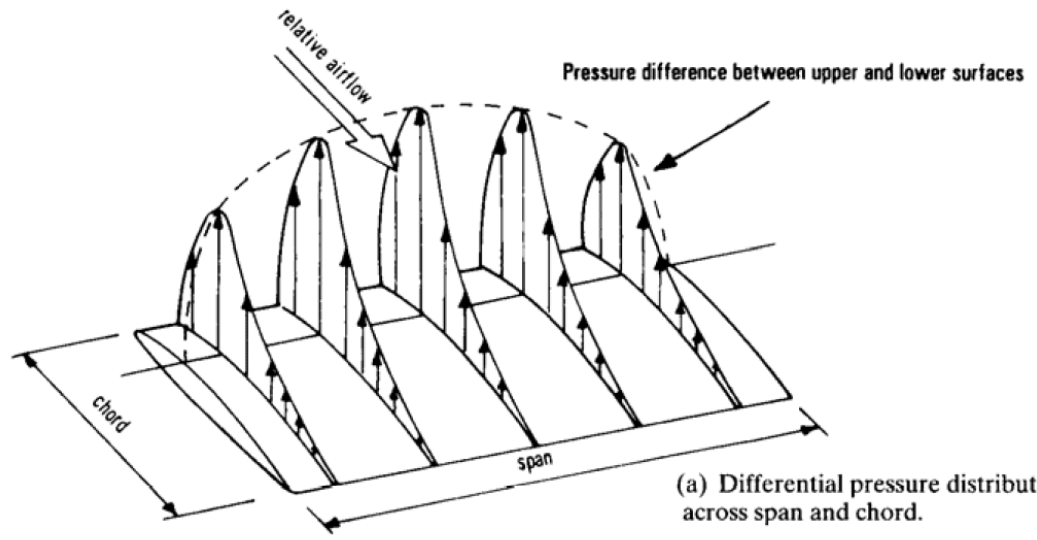
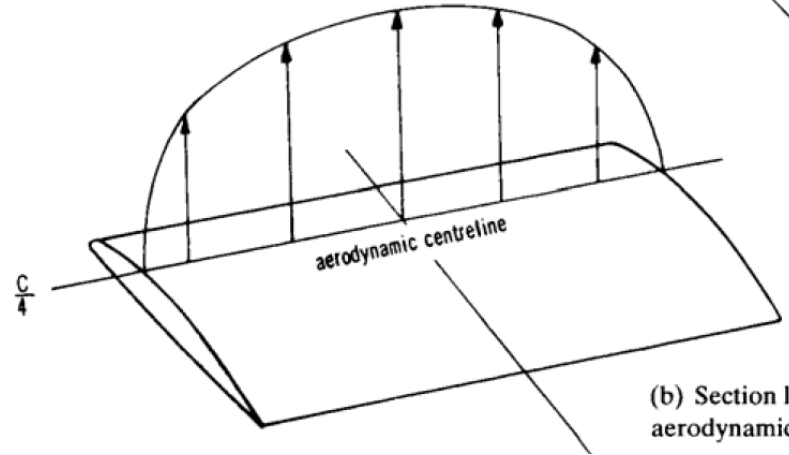


Fig. 5.1 The effect of an aeroplane upon a mass of air through which it has just passed.

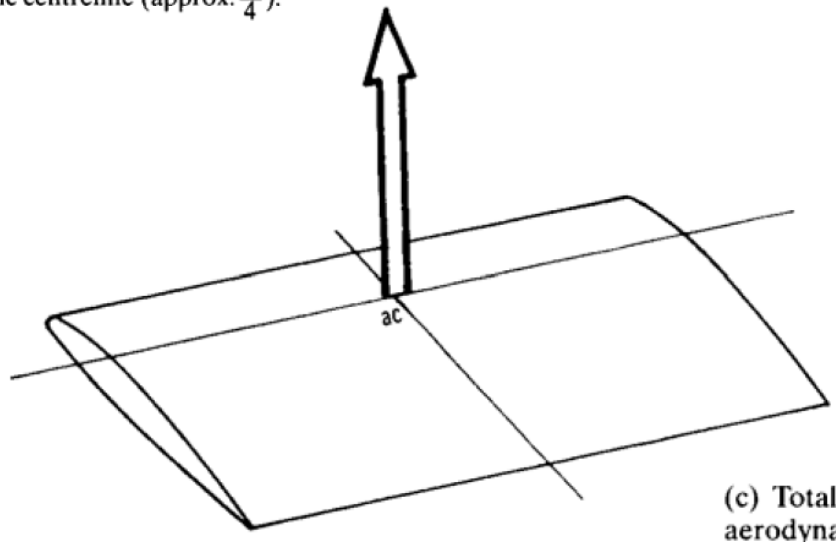
Ali finite, portanza



(a) Differential pressure distribution across span and chord.



(b) Section lift distribution acting along aerodynamic centreline (approx. $\frac{c}{4}$).



(c) Total lift acting through aerodynamic centre.

Ali finite, effetto dell'allungamento

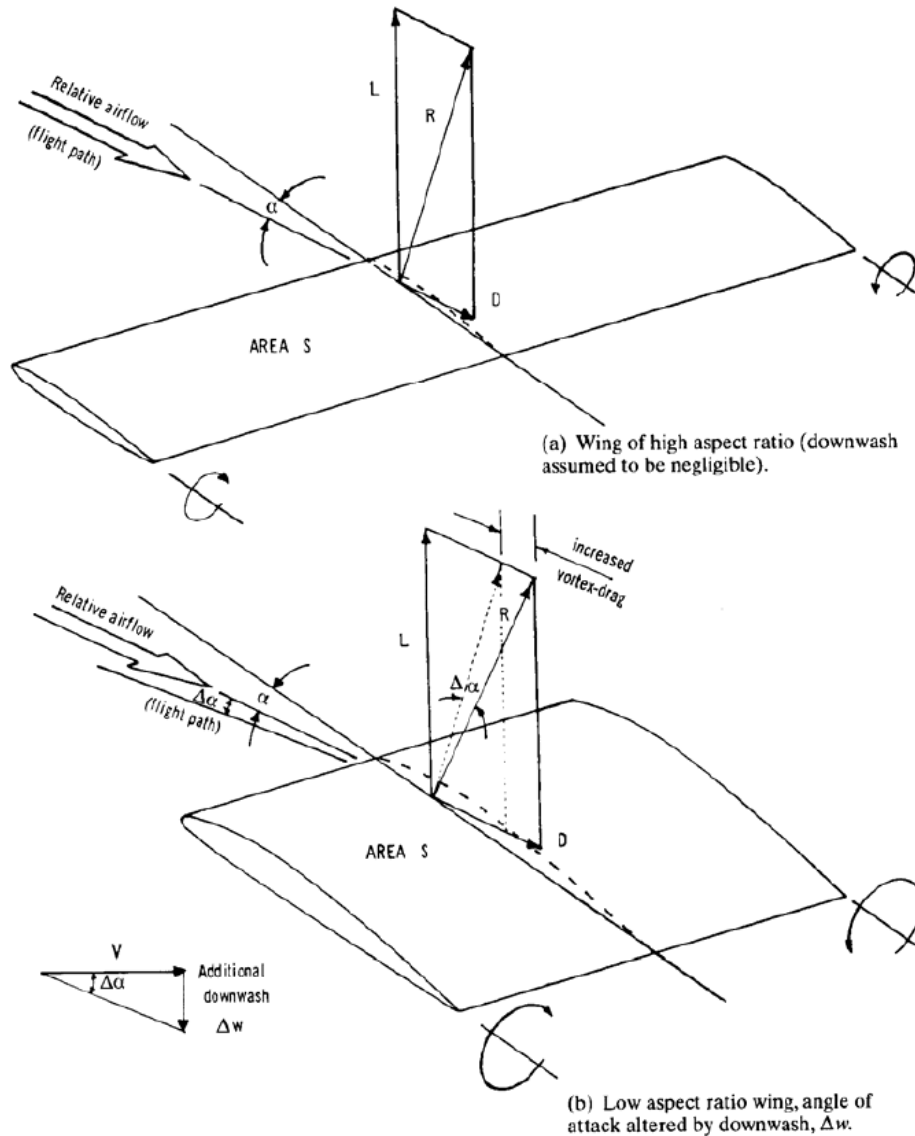
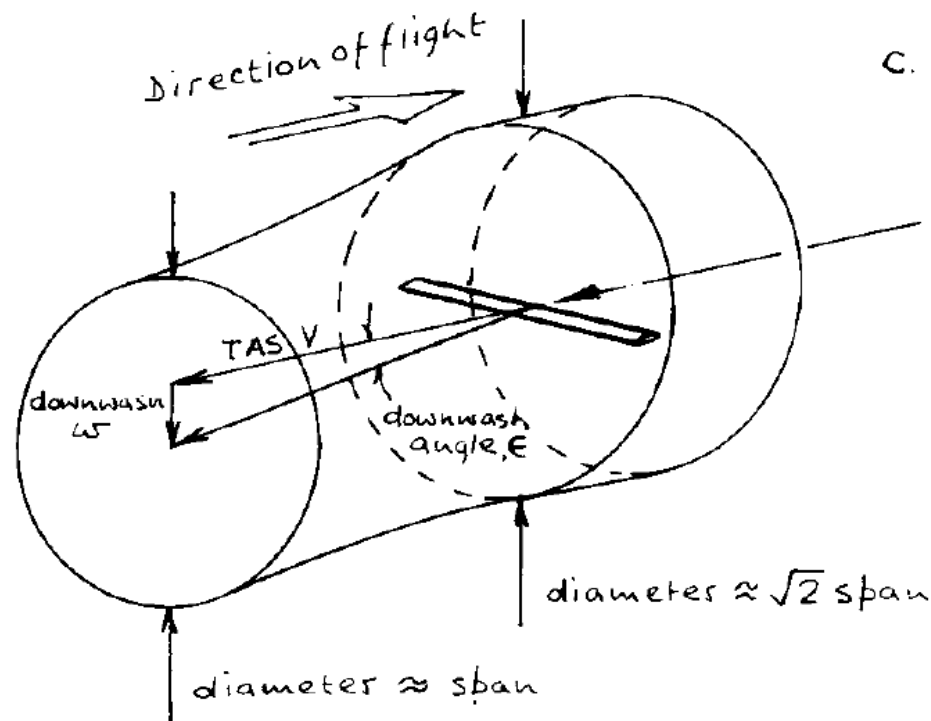


Fig. 5.12 The effect of aspect ratio upon wings of equal area generating equal lift (note increased attitude of low aspect ratio wing to flight path).

Ali finite, portanza e resistenza indotta

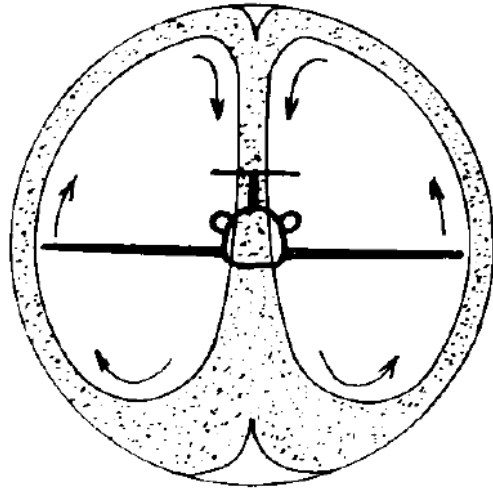


C. The mass of air shown in a. resembles a cylinder in elevation with a vena contracta form

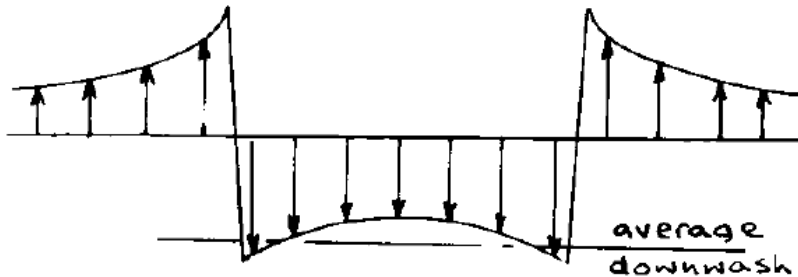
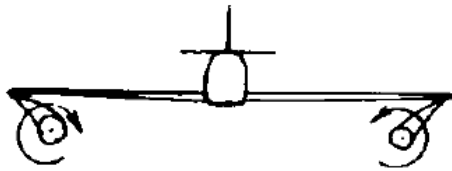
Fig 4-1

Fig. 4.1 The working mass of air acted upon by a wing in 1 second (after Lanchester and Prandtl)

Ali finite, sistema vorticoso



a. The mass of air worked on by a wing has a more or less circular cross-section with a diameter roughly equal to the span (see Eq(4-2)). Each lobe contains a vortex skein from a wing tip. Between them is a region of downwash of entrained air. Outside them is a corresponding upwash. The energy in the motion of the air is proportional to the energy needed to sustain the weight of the aeroplane. Thus, the wake of a heavy transport, flying slowly, or a helicopter, is most dangerous to light aircraft.



b. Each trailing vortex has a Rankine form, giving a spanwise downwash distribution like that shown (only the rare elliptical lift distribution across the span gives constant downwash between the vortex cores). The average downwash velocity at the wing is about 5ft/s (1.5m/s) for a light aeroplane, and 16ft/s (5m/s) for a big jet transport. Downwash far downstream in the wake may have double these values.

Ali finite, sistema vorticoso

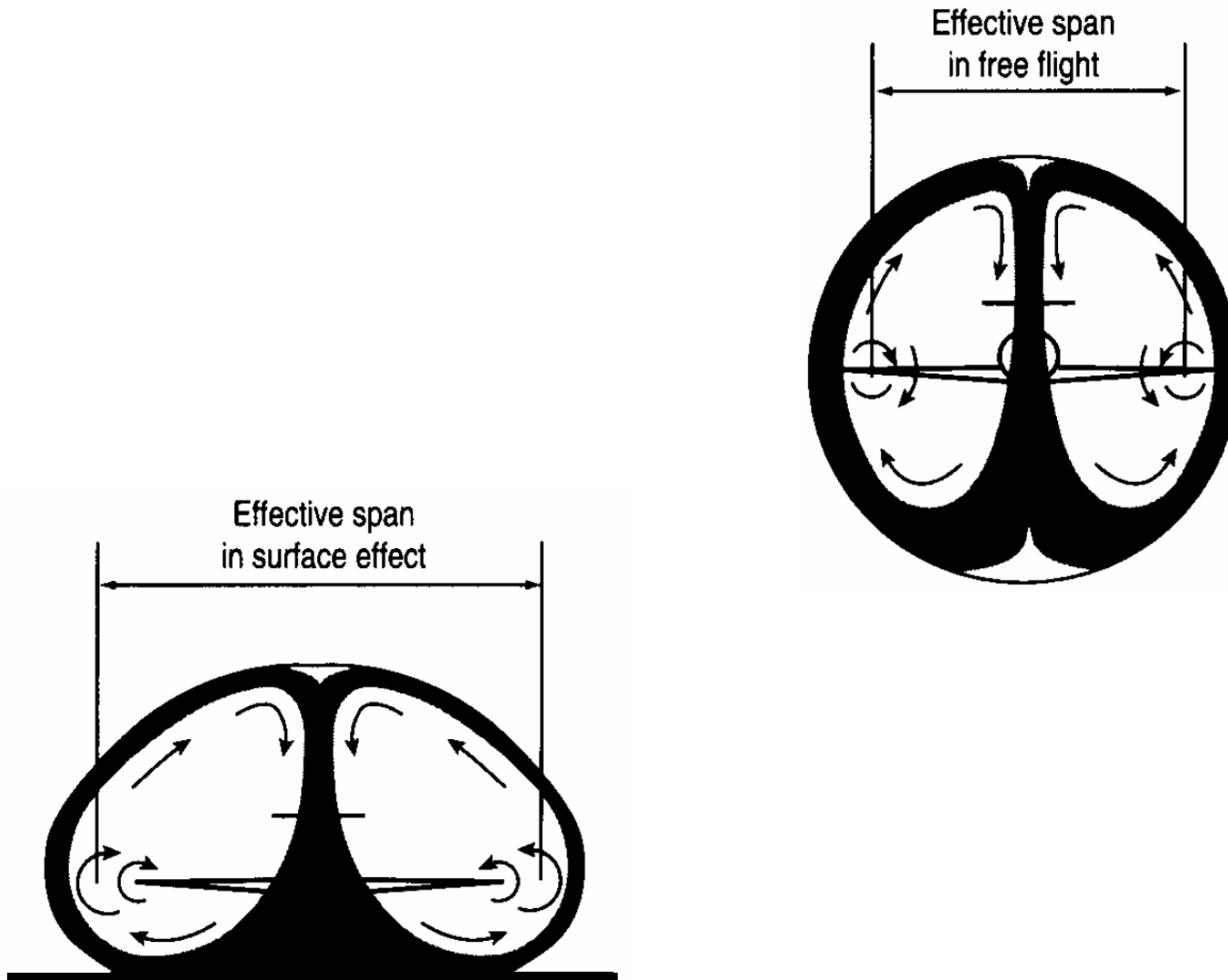
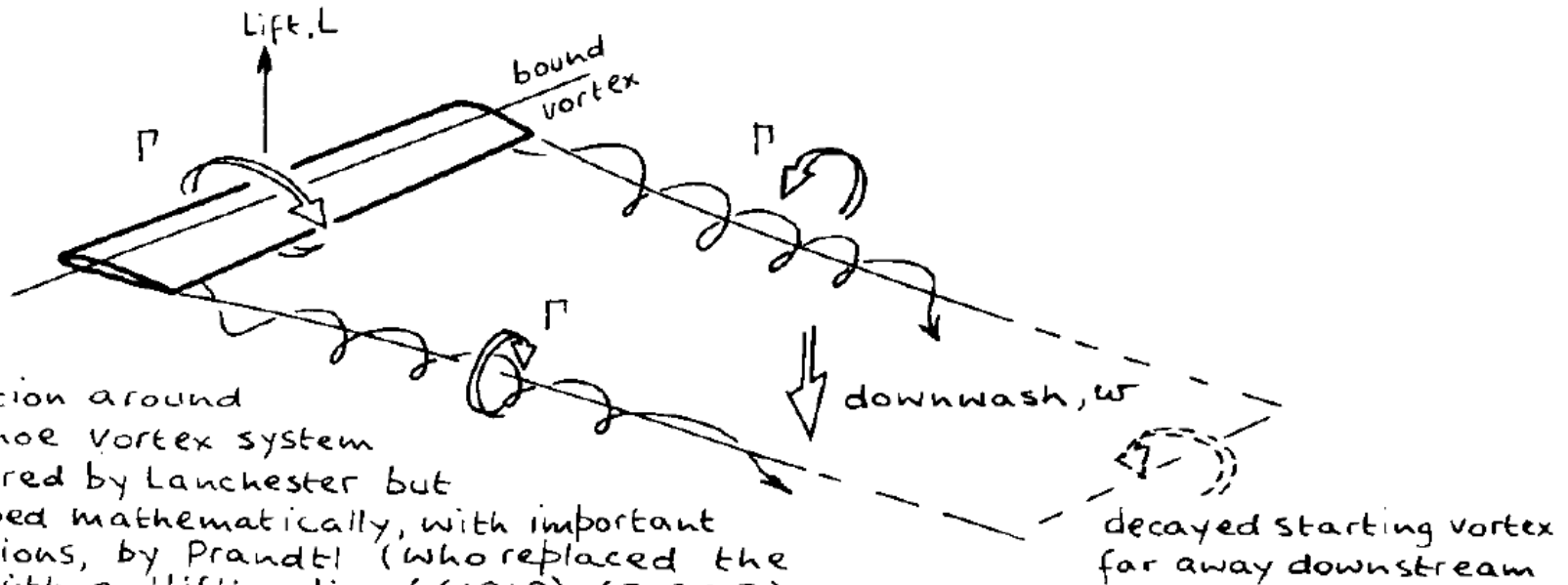


Fig. 5.12 (c) Ground or surface effect alters the cross-section of the mass of air being worked on by a wing, increasing the effective span and aspect ratio, so reducing lift-dependent (induced) drag.

Ali finite, sistema vorticoso



a. Circulation around horseshoe vortex system discovered by Lanchester but developed mathematically, with important variations, by Prandtl (who replaced the wing with a 'lifting line' (1918) (Ref 4.3))

$$\Gamma = \int_{\mathcal{C}} \mathbf{V} \cdot \mathbf{t} \, d\mathcal{C}$$

Circolazione del campo di velocità

$$l = \rho_{\infty} V_{\infty} \Gamma$$

Kutta-Joukowski

Ali finite, sistema vorticoso

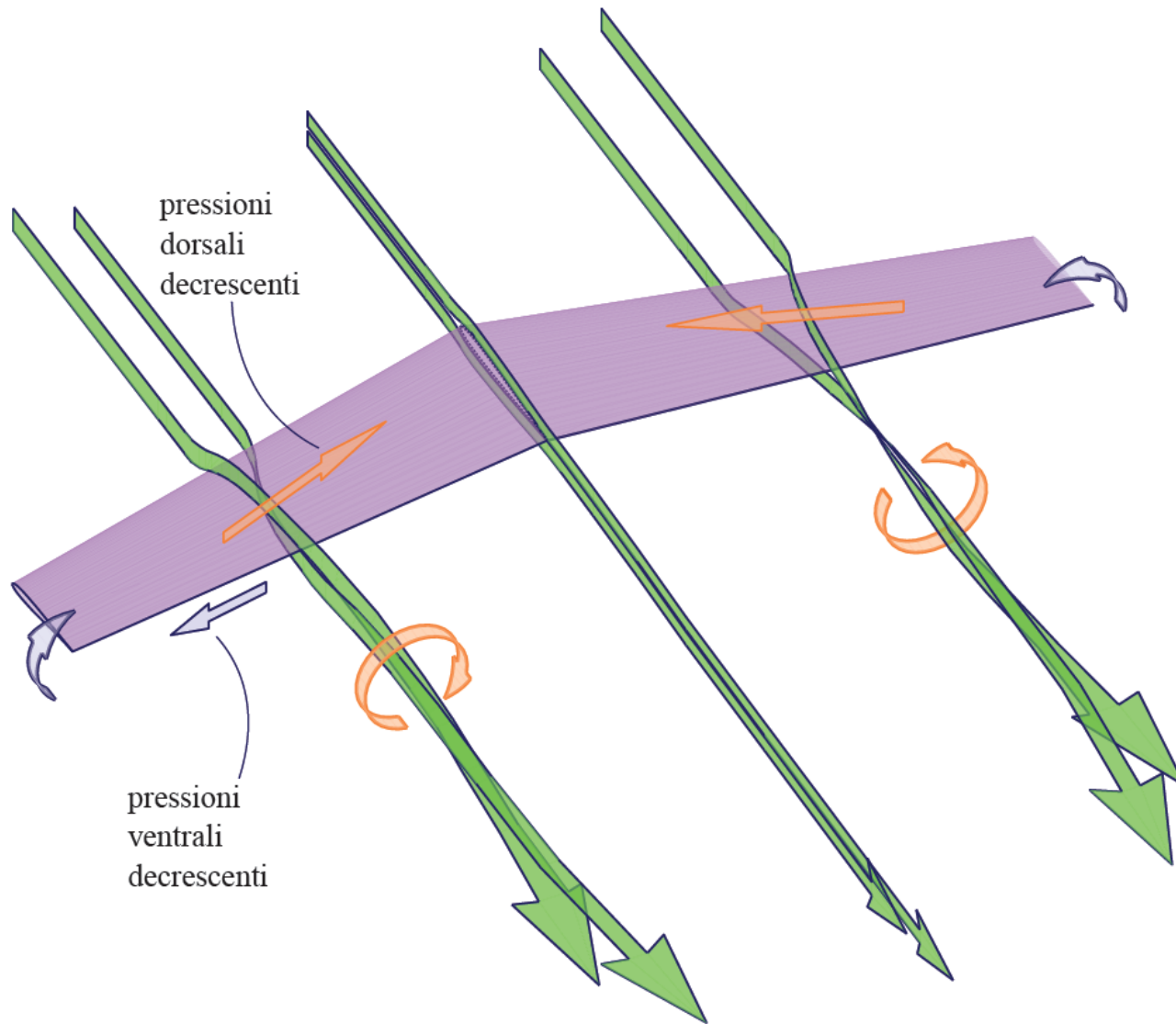
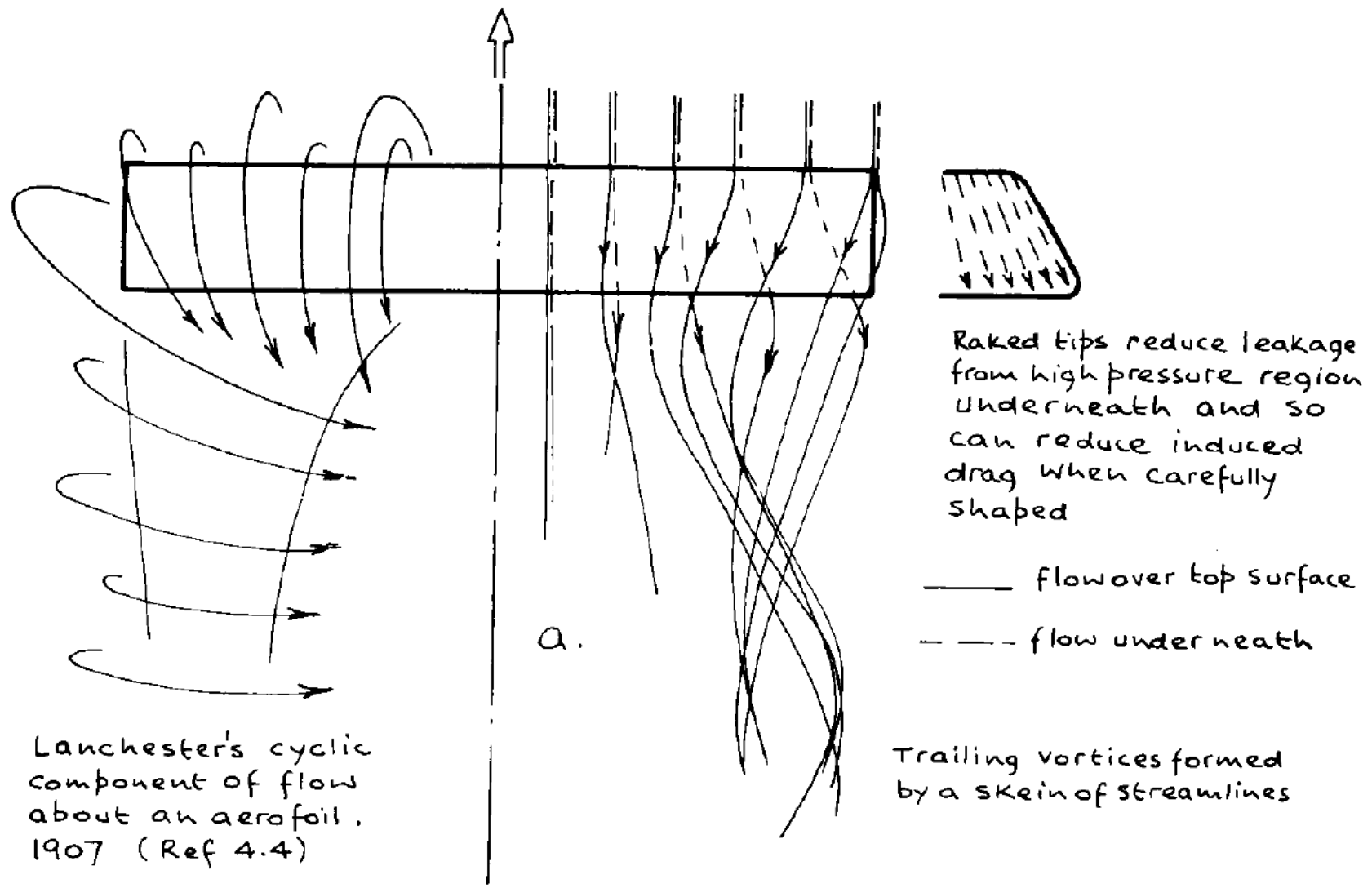


Figura 4.6 Genesi della rotazionalità e della scia vorticoso a valle di un'ala finita.

Ali finite, sistema vorticoso



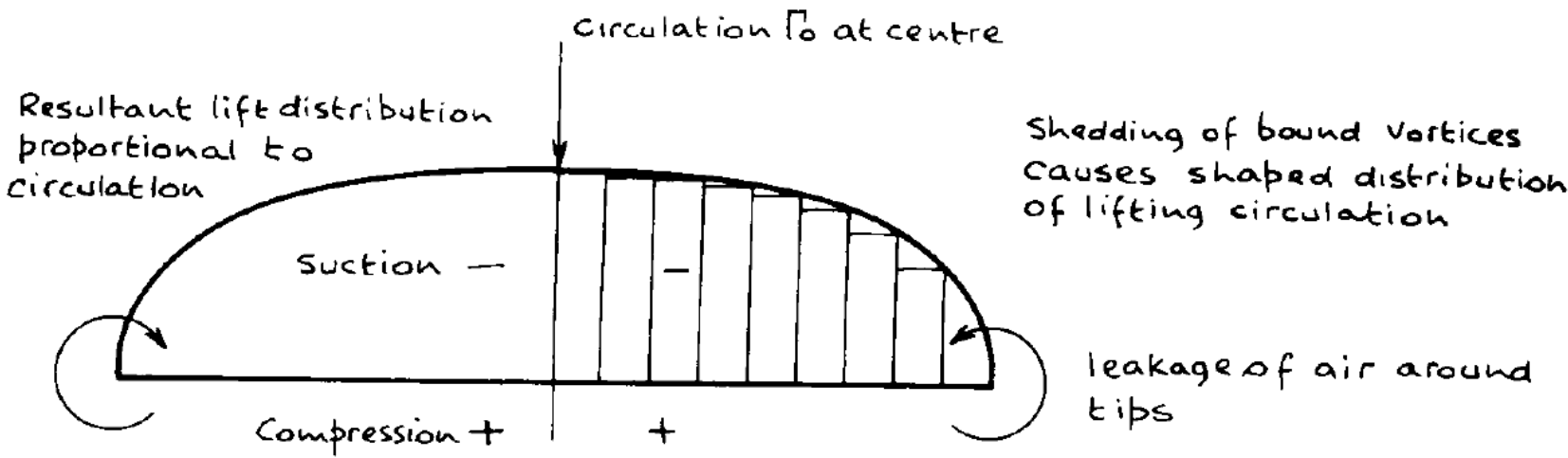
Lanchester's cyclic component of flow about an aerofoil. 1907 (Ref 4.4)

Raked tips reduce leakage from high pressure region underneath and so can reduce induced drag when carefully shaped

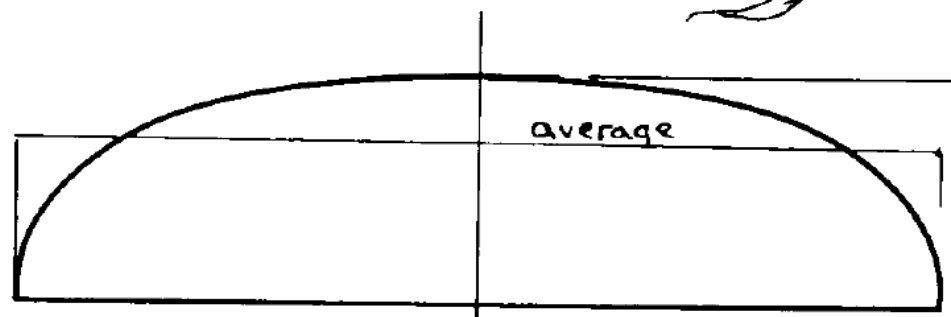
— flow over top surface
 - - - flow underneath

Trailing vortices formed by a skein of streamlines

Ali finite, vorticità



b.



c.

$\Gamma_0 = 4 \Gamma / \pi$ when distribution is elliptical

Ali finite, effetto dell'allungamento

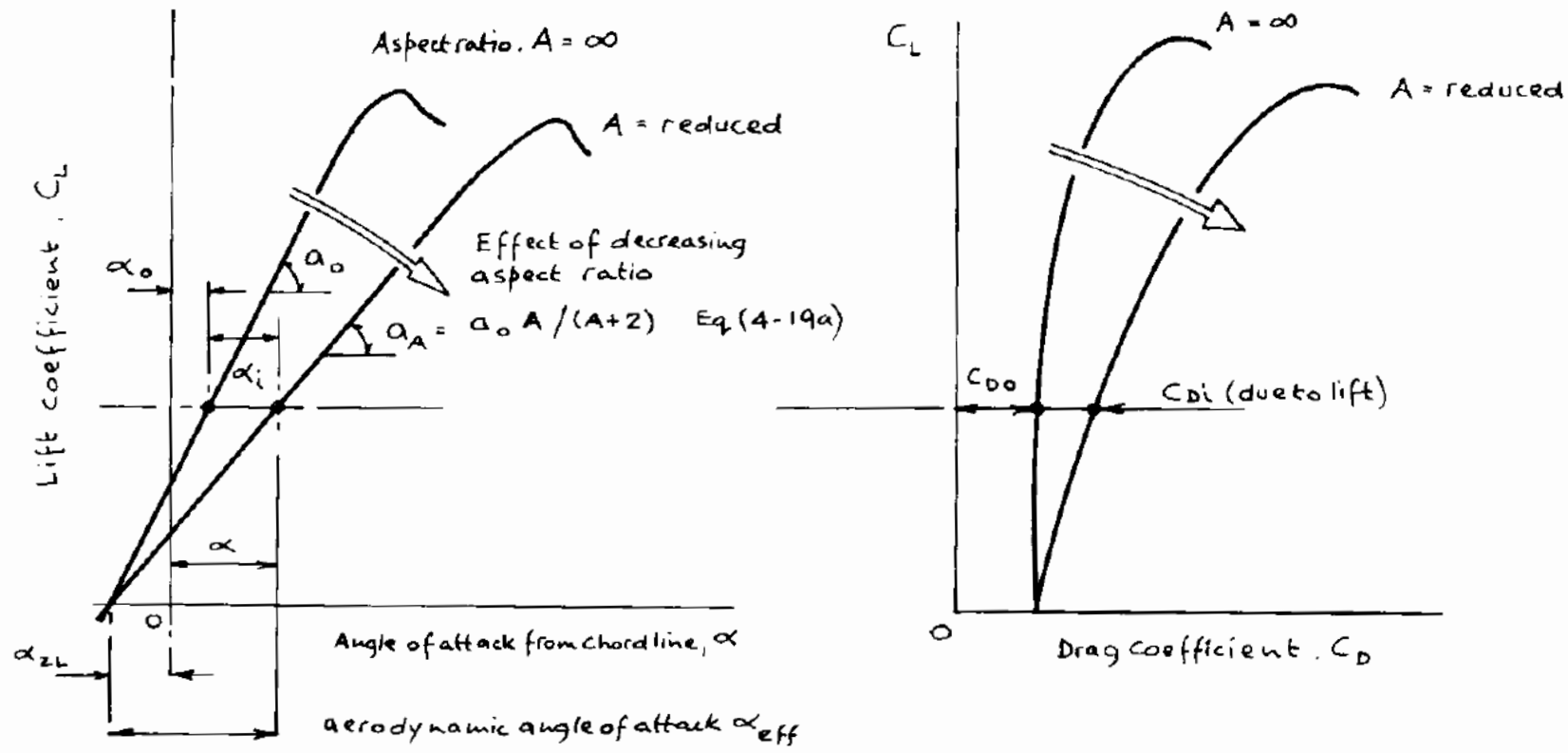


Fig. 4.6 Effect of aspect ratio, A , upon lift and drag characteristics.

Ali finite, gradiente della retta di portanza

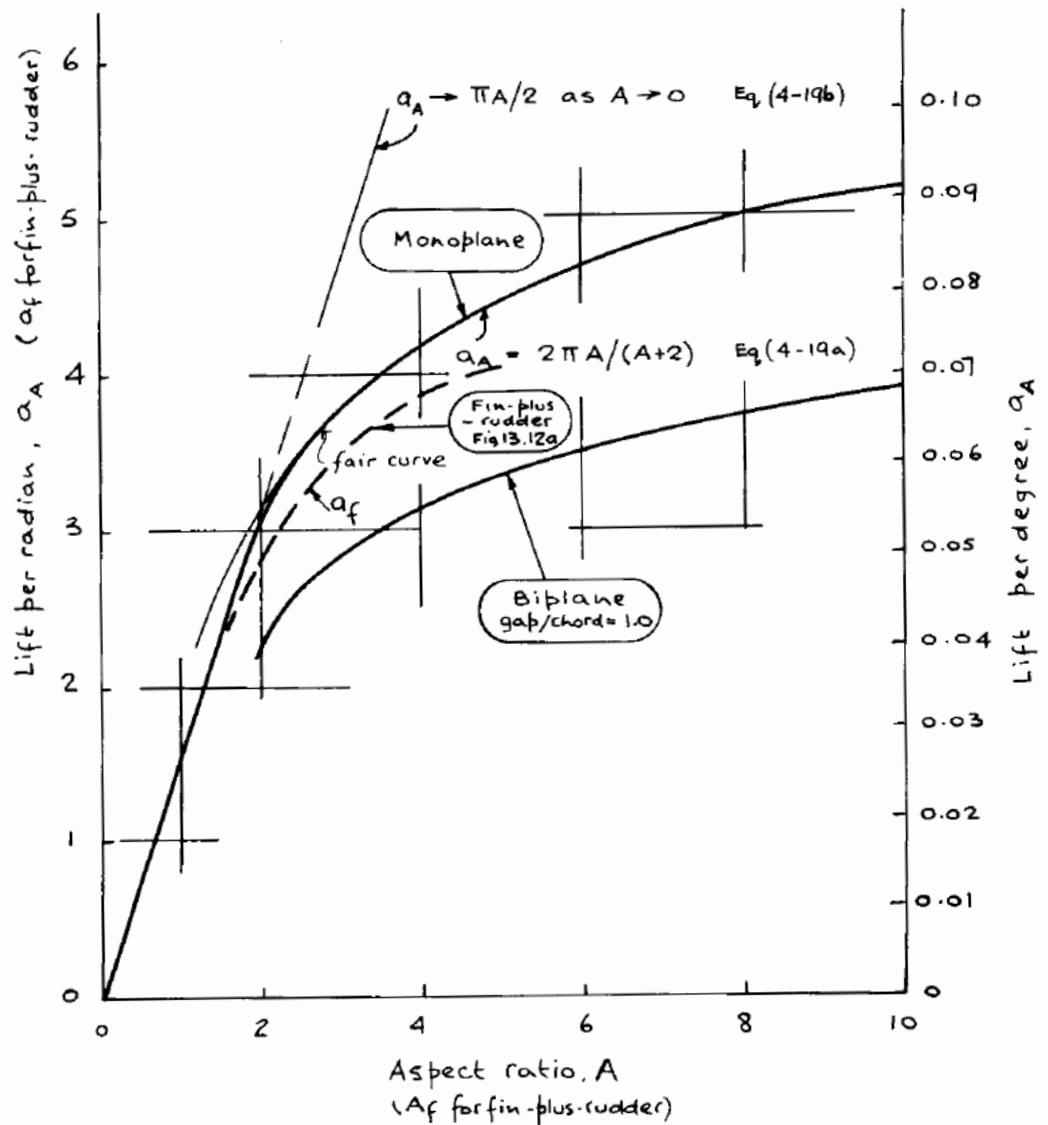


Fig. 4.6c Effect of aspect ratio upon lift slope, α_A . This figure ignores the influence of form factor due to taper, eq (5-5) and fig. 5.5.

Ali finite, vortici liberi

Kutta-Joukowski

Espressione convenzionale

$$l(Y) = \rho_{\infty} V_{\infty} \Gamma(Y) = C_l(Y) \frac{1}{2} \rho_{\infty} V_{\infty}^2 c(Y)$$

Carico:

$$\gamma(Y) = \frac{\Gamma(Y)}{bV_{\infty}} = \frac{c(Y)C_l(Y)}{2b}$$

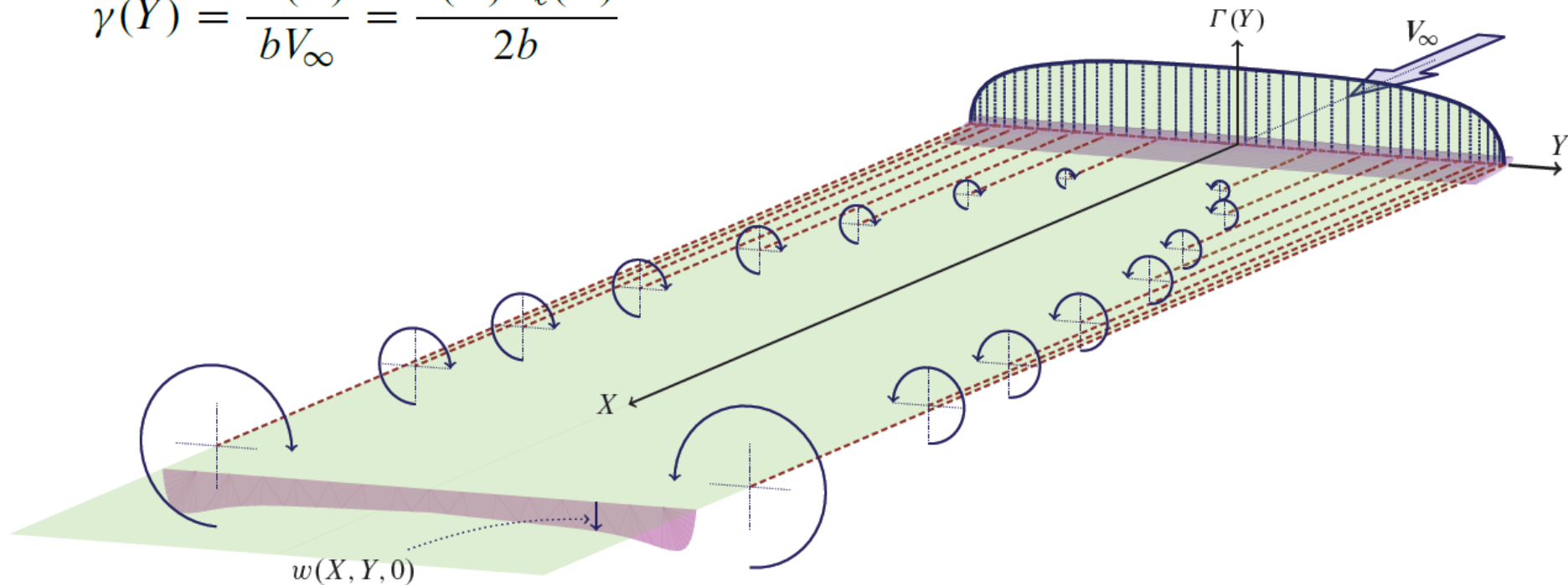
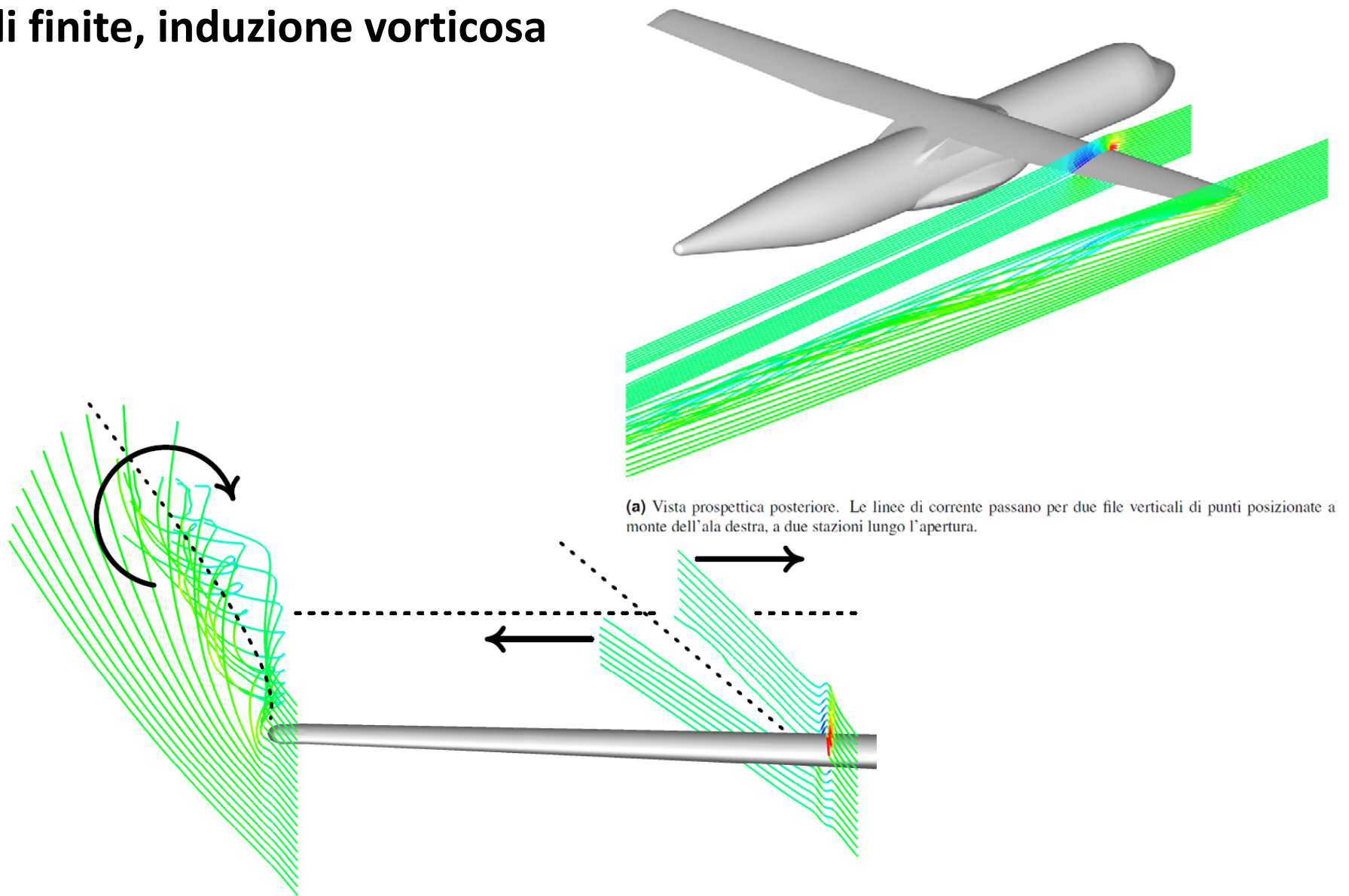


Figura 4.7 Schematizzazione approssimata della scia vorticosa a valle di un'ala finita nella teoria alare di Prandtl. I vortici liberi si estendono indefinitamente a valle, sono paralleli alla velocità asintotica e sono contenuti in un piano che contiene la linea dei fuochi.

Ali finite, induzione vorticososa



(a) Vista prospettica posteriore. Le linee di corrente passano per due file verticali di punti posizionate a monte dell'ala destra, a due stazioni lungo l'apertura.

(b) Vista prospettica anteriore dell'ala. Le linee di corrente esterne che lambiscono l'estremità alare vengono deviate vistosamente per effetto della forte induzione vorticososa in quella regione. Tra le linee di corrente interne che investono l'ala si evidenzia il tipico scorrimento verso l'interno di quelle linee che si diramano dalla parte del dorso. Al contrario, le linee che si diramano dalla parte del ventre scorrono verso l'esterno.

Ali finite, induzione vorticososa

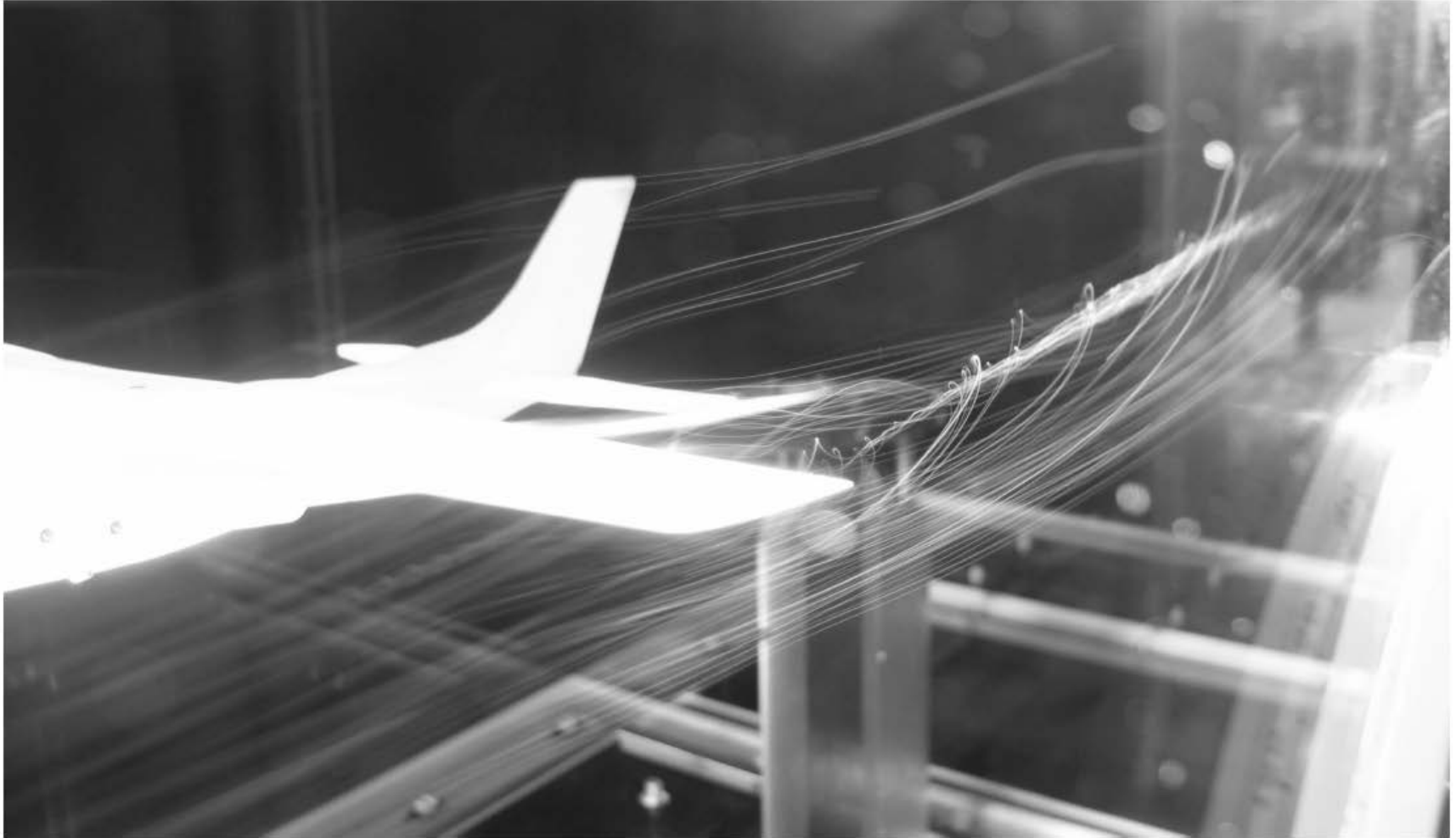


Figura 4.9 Sperimentazione in galleria del vento su un modello di velivolo dell'aviazione generale. Visualizzazione del vortice d'estremità sinistro.

Ali finite, induzione vorticososa



Figura 4.10 Vortici d'estremità visibili ad occhio nudo in particolari condizioni atmosferiche.

Ali finite

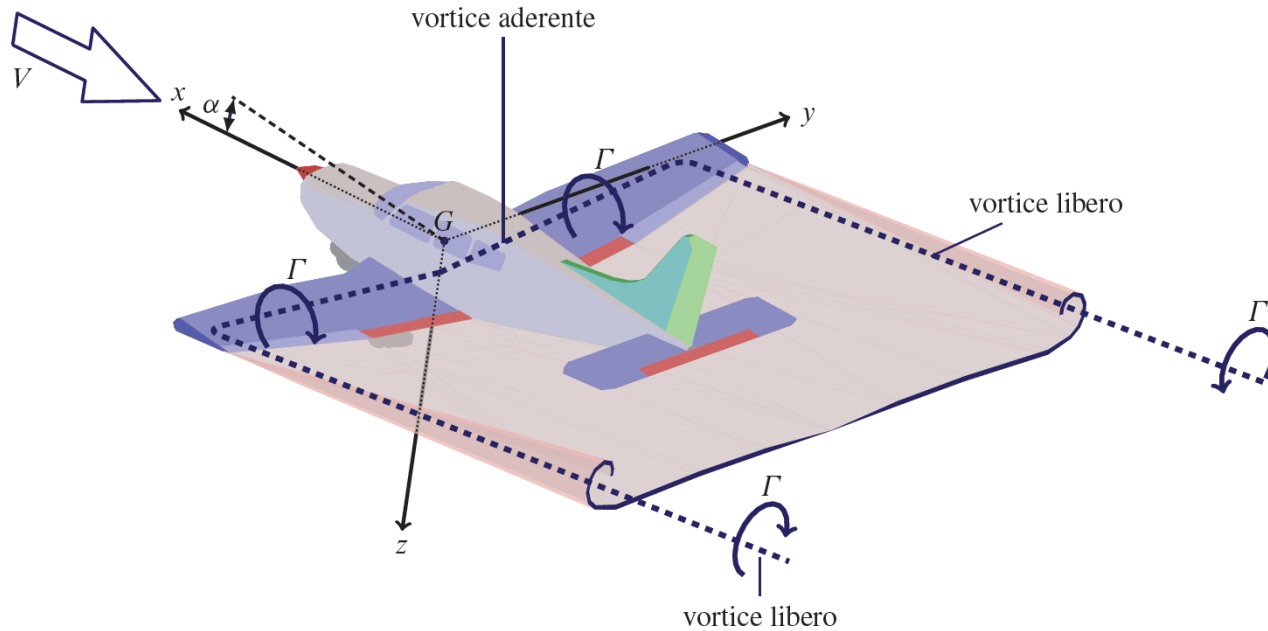


Figura 4.13 Schematizzazione della scia vorticoso a valle di un'ala finita portante con un vortice "a staffa" di intensità costante. La parte trasversale rappresenta l'ala e le due parti longitudinali rappresentano i nuclei vorticosi d'estremità.

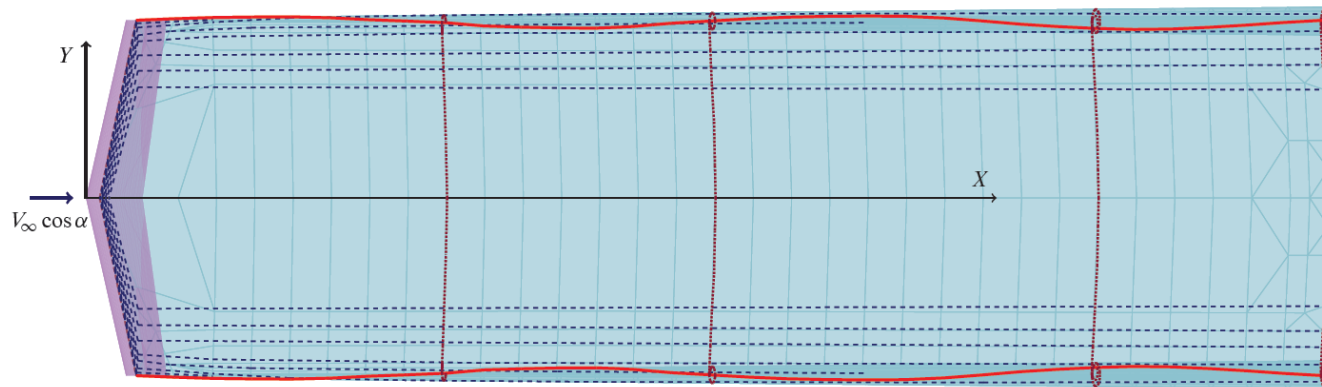


Figura 4.12 Vista dall'alto dei vortici aderenti e vortici liberi. La variazione di intensità della circolazione lungo l'apertura dà luogo al distacco di vortici liberi nella scia a valle dell'ala.

Ali finite, scia vorticososa

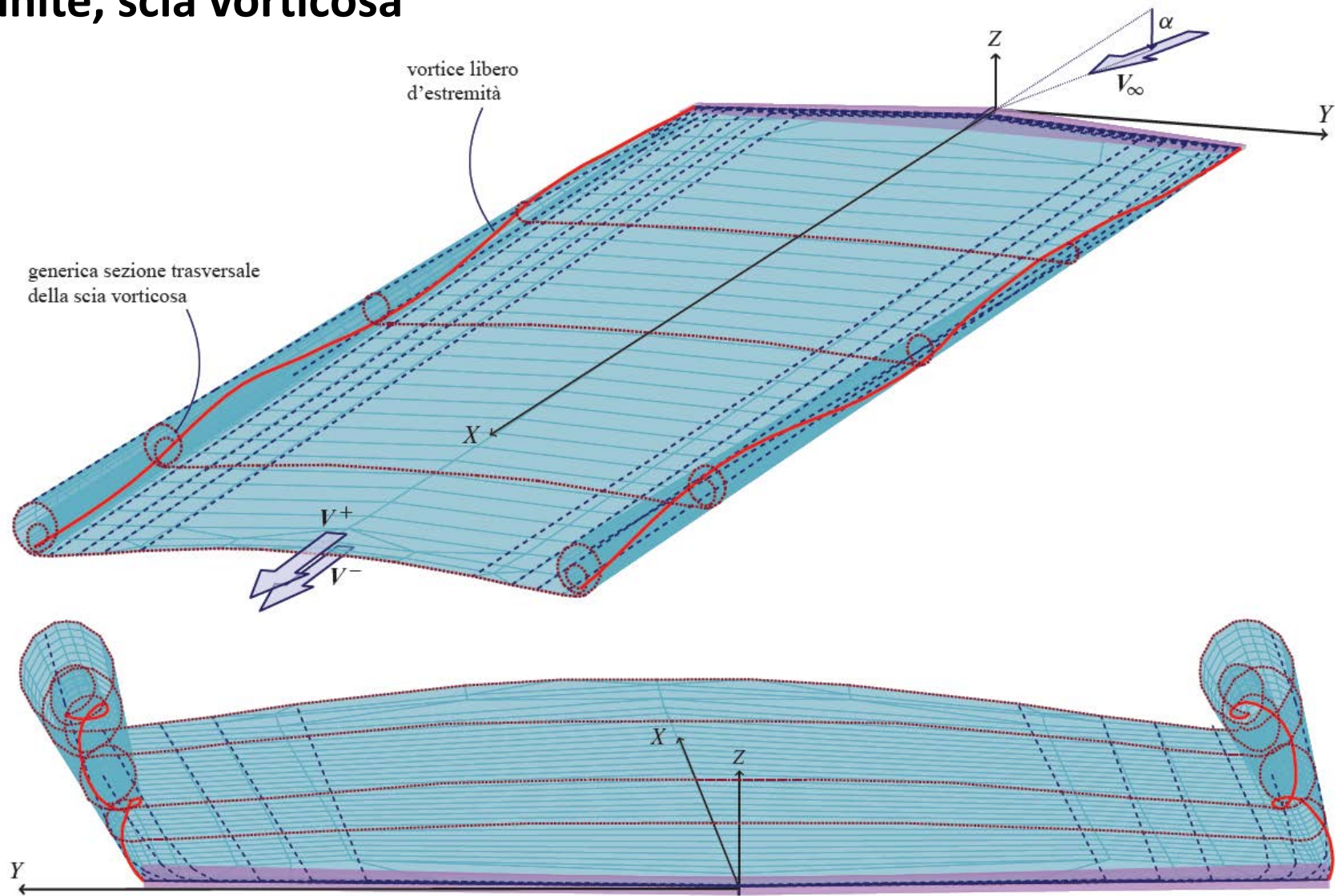


Figura 4.14 Schematizzazione della scia vorticososa a valle di un'ala finita portante. Per la tendenza dei vortici liberi ad arrotolarsi (*rolling-up*) vengono a formarsi due distinti nuclei vorticosi concentrici.

Ali finite, *downwash* sulla linea dei fuochi

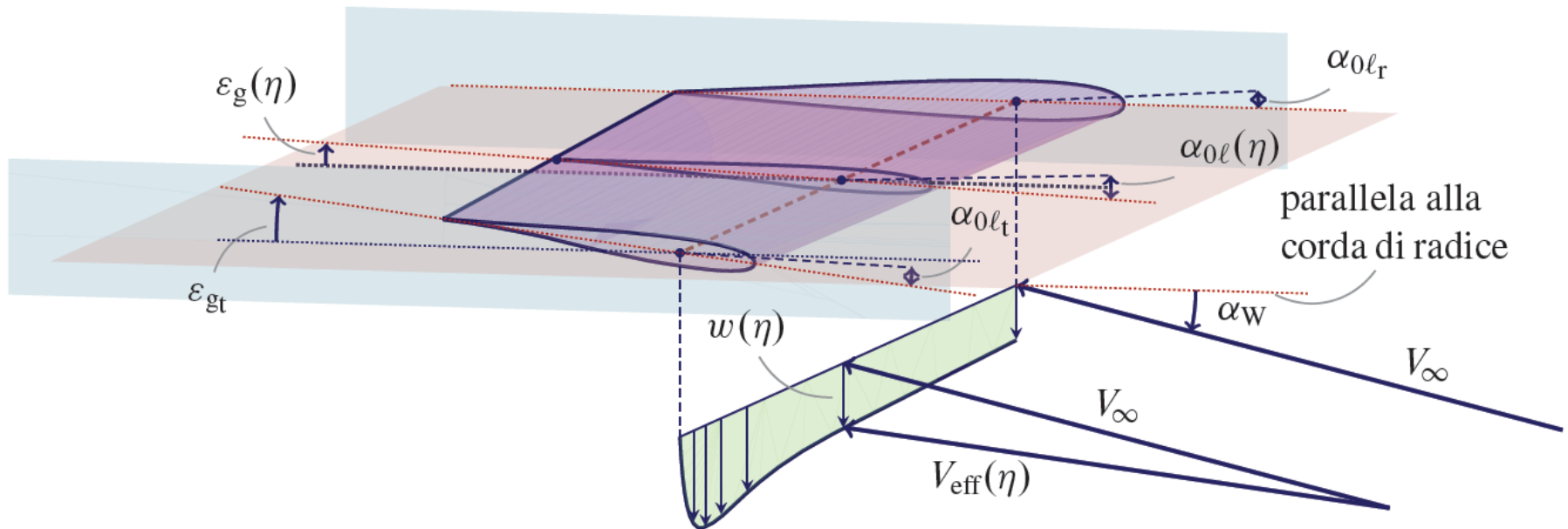
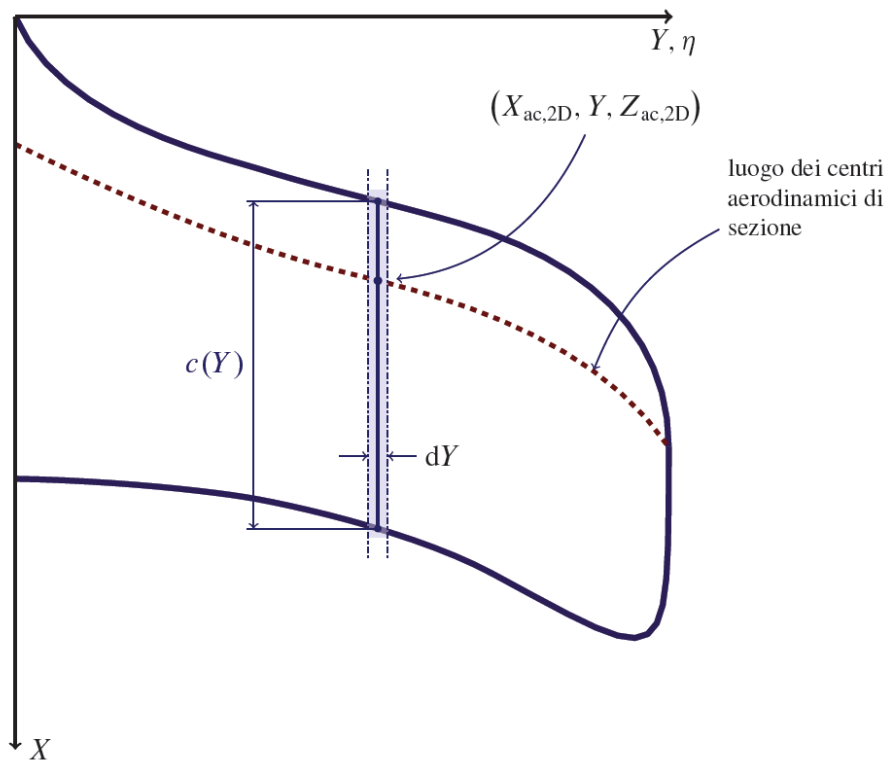


Figura 4.39 *Downwash* in corrispondenza della linea dei fuochi di un'ala dritta.

Ali finite, calcolo della c.m.a.



$$\bar{c} = \frac{2}{S} \int_0^{b/2} c^2 dY \quad \text{c.m.a.}$$

$$P_{ac,2D} \equiv (X_{ac,2D}, Y, Z_{ac,2D})$$

$$C_{\ell_a}(Y) = C_L \cdot C_{\ell_{a1}}(Y) \quad \text{addizionale}$$

$$C_{\ell_b}(Y) \quad \text{basico}$$

Coordinate del centro aerodinamico:

$$\bar{X} = \frac{2}{C_L S} \int_0^{b/2} C_{\ell_a}(Y) c(Y) X_{ac,2D}(Y) dY$$

$$\bar{Y} = \frac{2}{C_L S} \int_0^{b/2} C_{\ell_a}(Y) c(Y) Y dY = \frac{b}{2} \eta_{cp}$$

$$\bar{Z} = \frac{2}{C_L S} \int_0^{b/2} C_{\ell_a}(Y) c(Y) Z_{ac,2D}(Y) dY$$

$(C_{M_0})_W$ Coeff. Momento focale

$$\bar{X} = n c_r + \bar{Y} \tan \Lambda_n$$

$$n = \frac{1}{4}$$

$$n = \frac{1}{2}$$

Ali finite, calcolo della c.m.a.

$$\bar{c} = \frac{2}{3} \frac{1 + \lambda + \lambda^2}{1 + \lambda} c_r$$

$$X_{\bar{c}/4} = \left(\frac{1 + 2\lambda}{12} \mathcal{R} \tan \Lambda_{l.e.} + \frac{1}{4} \frac{\bar{c}}{c_r} \right) c_r$$

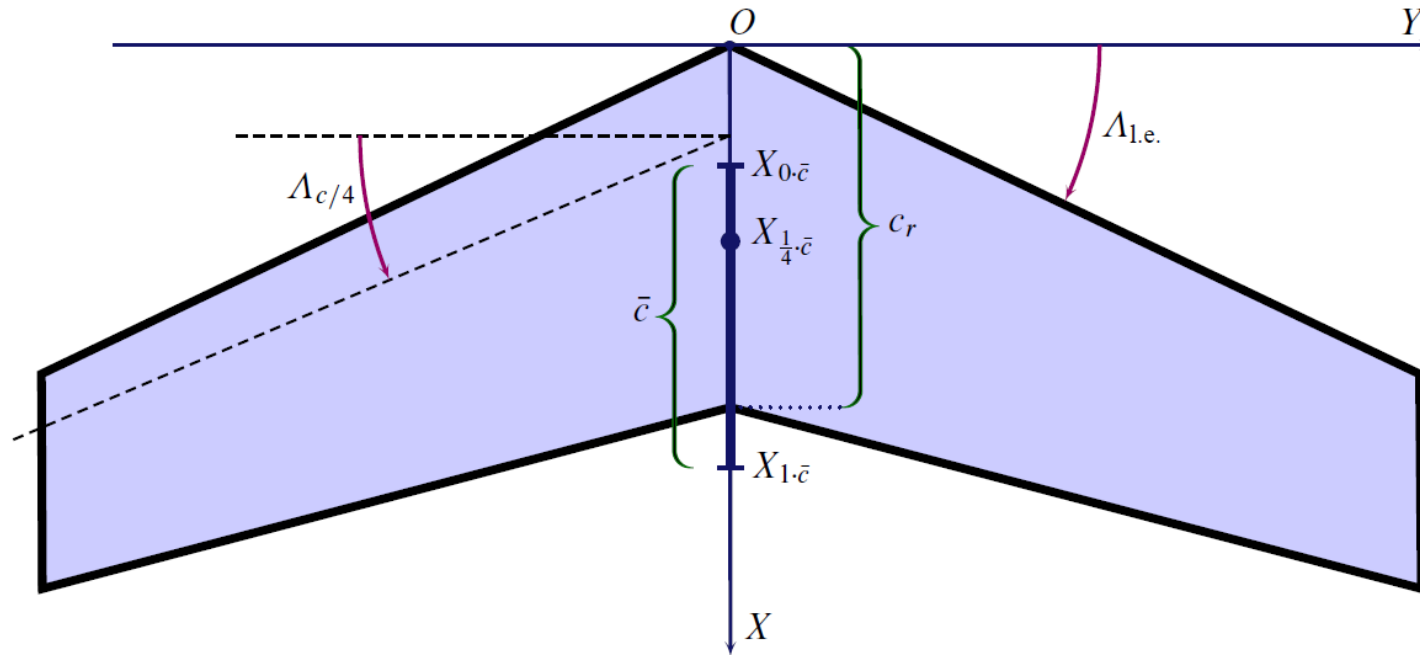


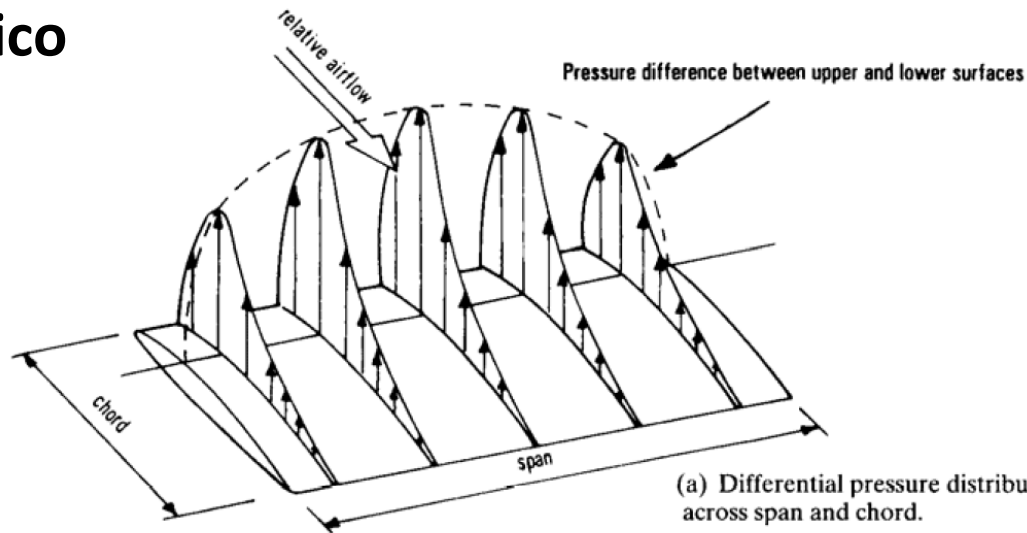
Figura 4.34 Forma in pianta di un'ala con bordi dritti e corda media aerodinamica \bar{c} .

$$\mathcal{R} \tan \Lambda_n = \mathcal{R} \tan \Lambda_m + 4(m - n) \frac{1 - \lambda}{1 + \lambda}$$

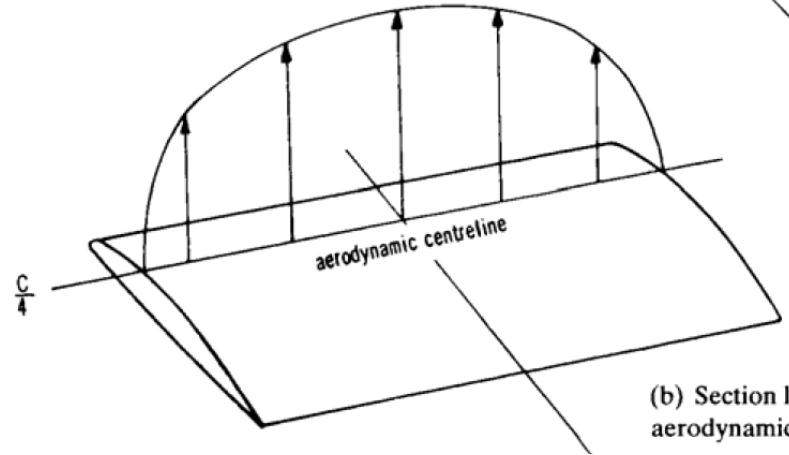
$$\tan \Lambda_{l.e.} = \tan \Lambda_{c/4} - \frac{1}{\mathcal{R}} \frac{1 - \lambda}{1 + \lambda}$$

\uparrow $n = 0$ \uparrow $m = \frac{1}{4}$

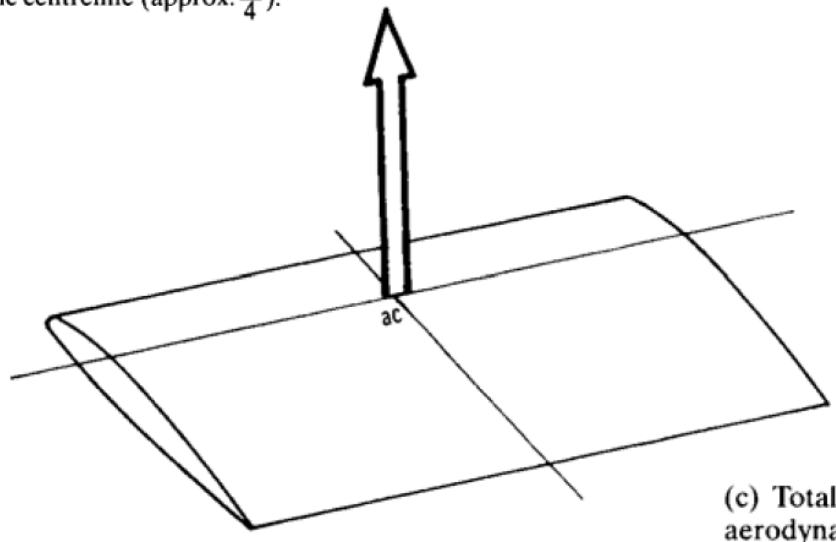
Ali finite, centro aerodinamico



(a) Differential pressure distribution across span and chord.



(b) Section lift distribution acting along aerodynamic centreline (approx. $\frac{c}{4}$).



(c) Total lift acting through aerodynamic centre.

Ali finite

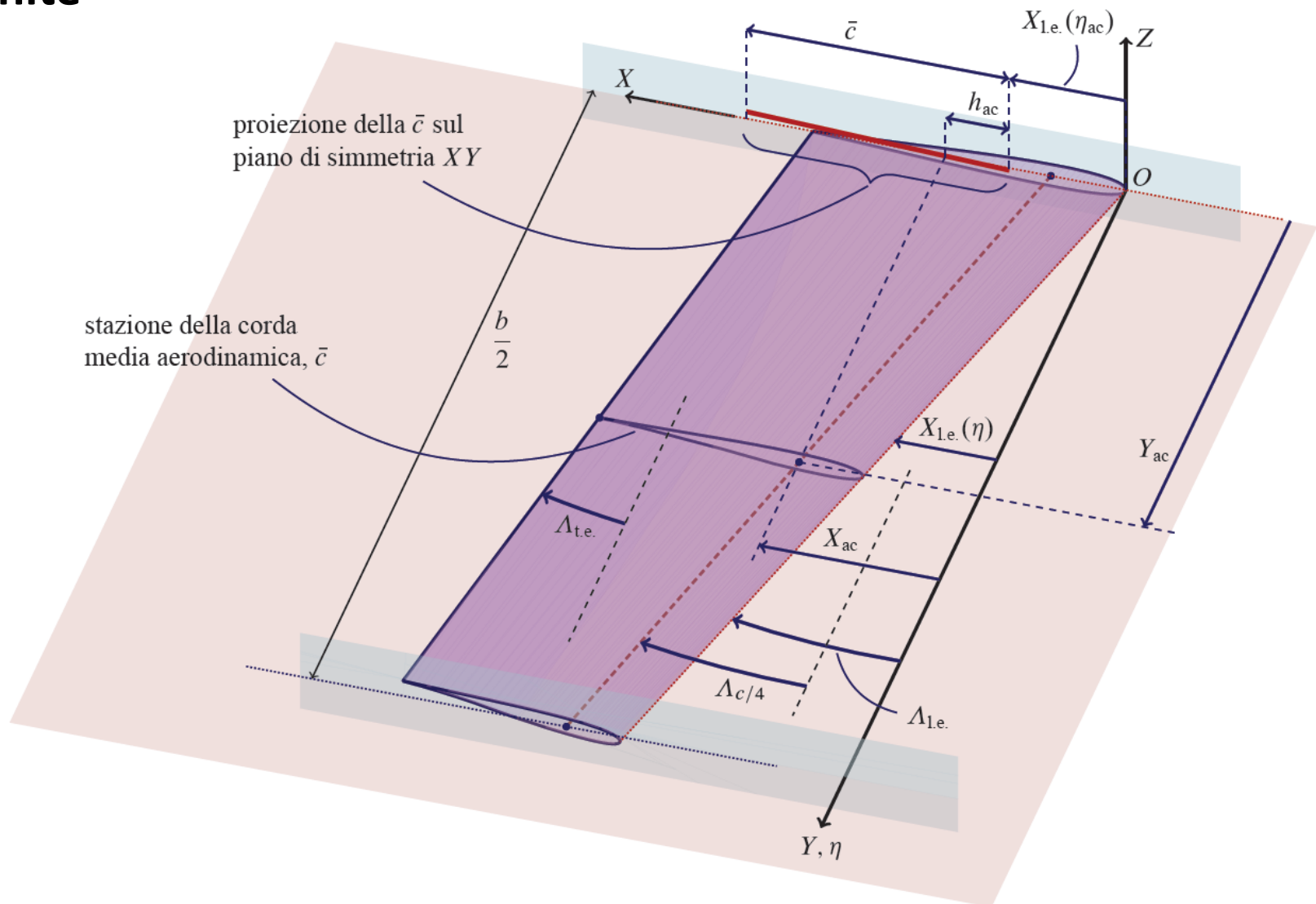


Figura 4.38 Corda media aerodinamica di un'ala con bordi dritti.

Ali finite, determinazione grafica del centro aerodinamico

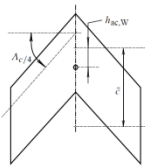
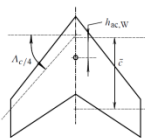
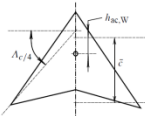
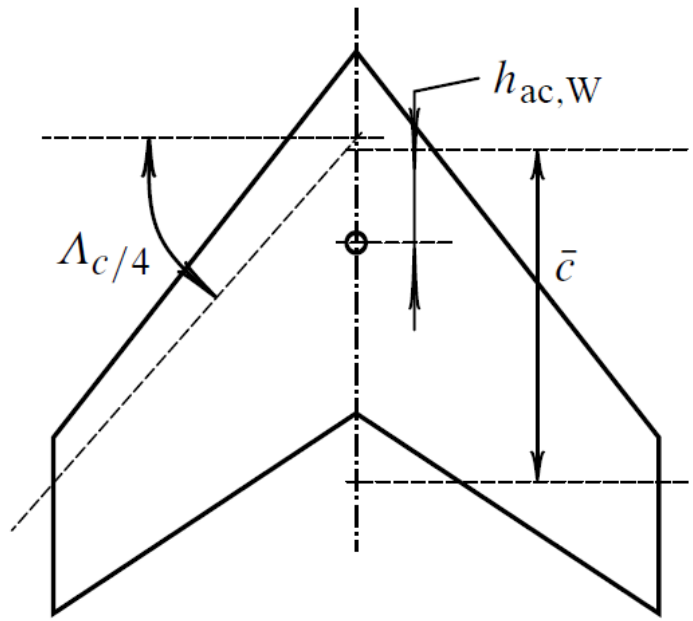
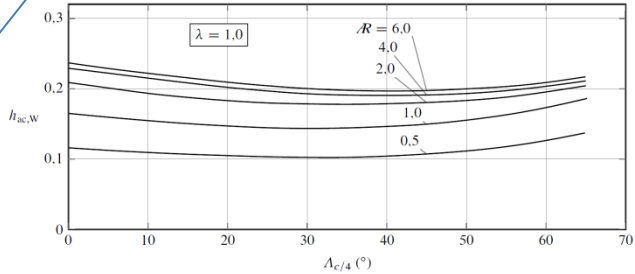
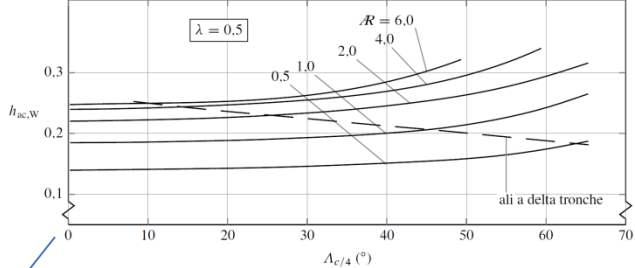
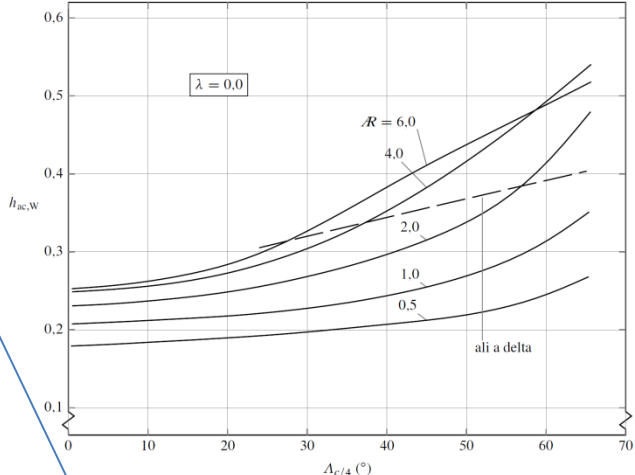
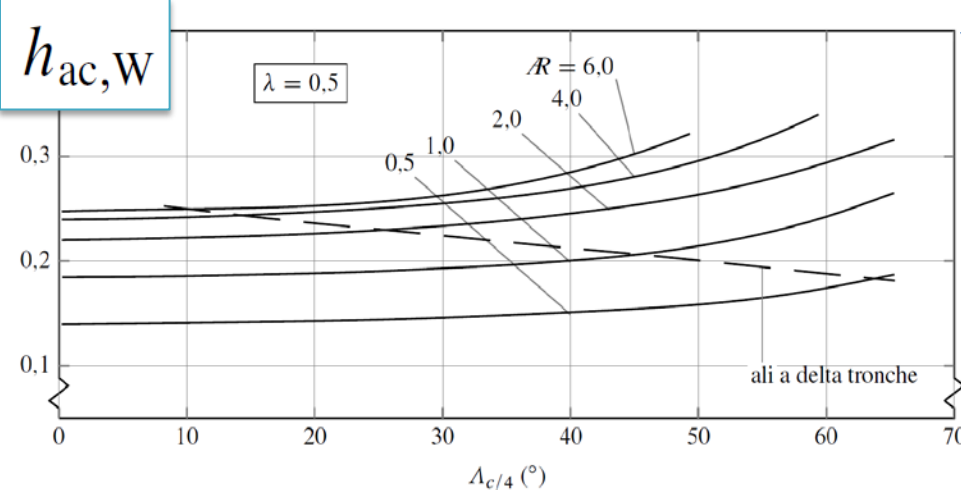
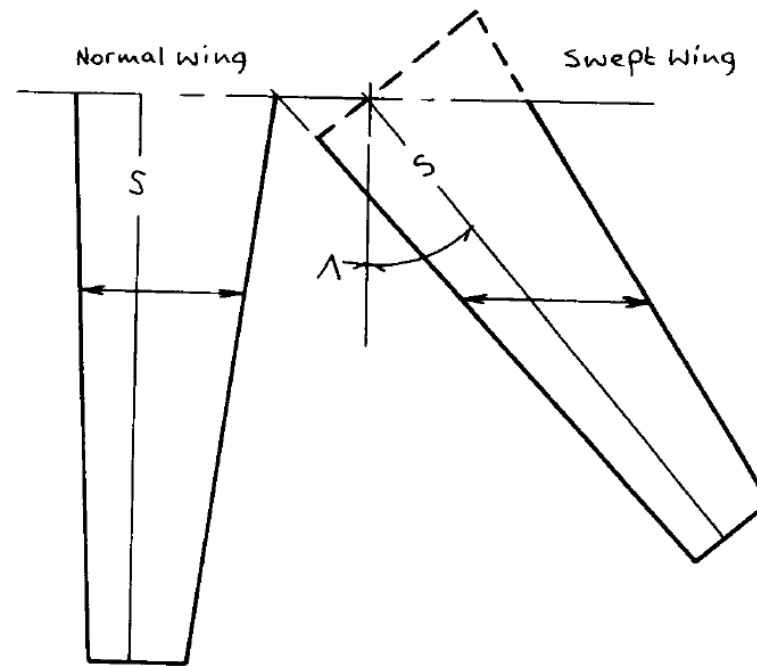
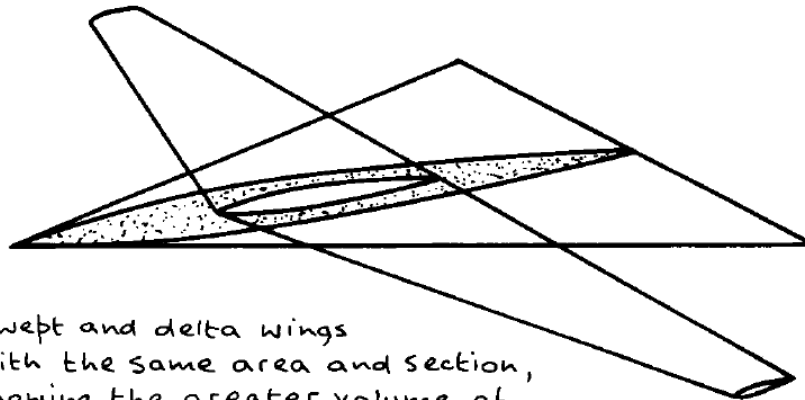


Figura 4.35 Posizione del centro aerodinamico rispetto alla corda media aerodinamica per ali finite con bordi dritti. Le curve mostrano la variazione di $h_{ac,W}$ per diversi allungamenti, angoli di freccia e rapporti di rastremazione.

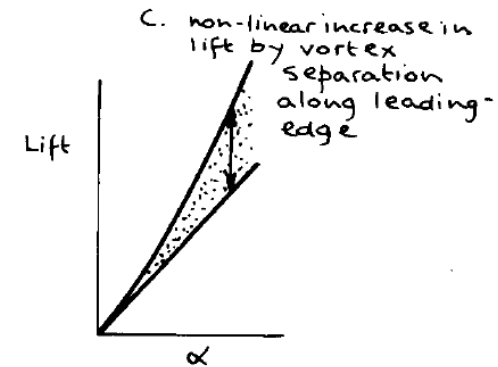
Ali finite, freccia



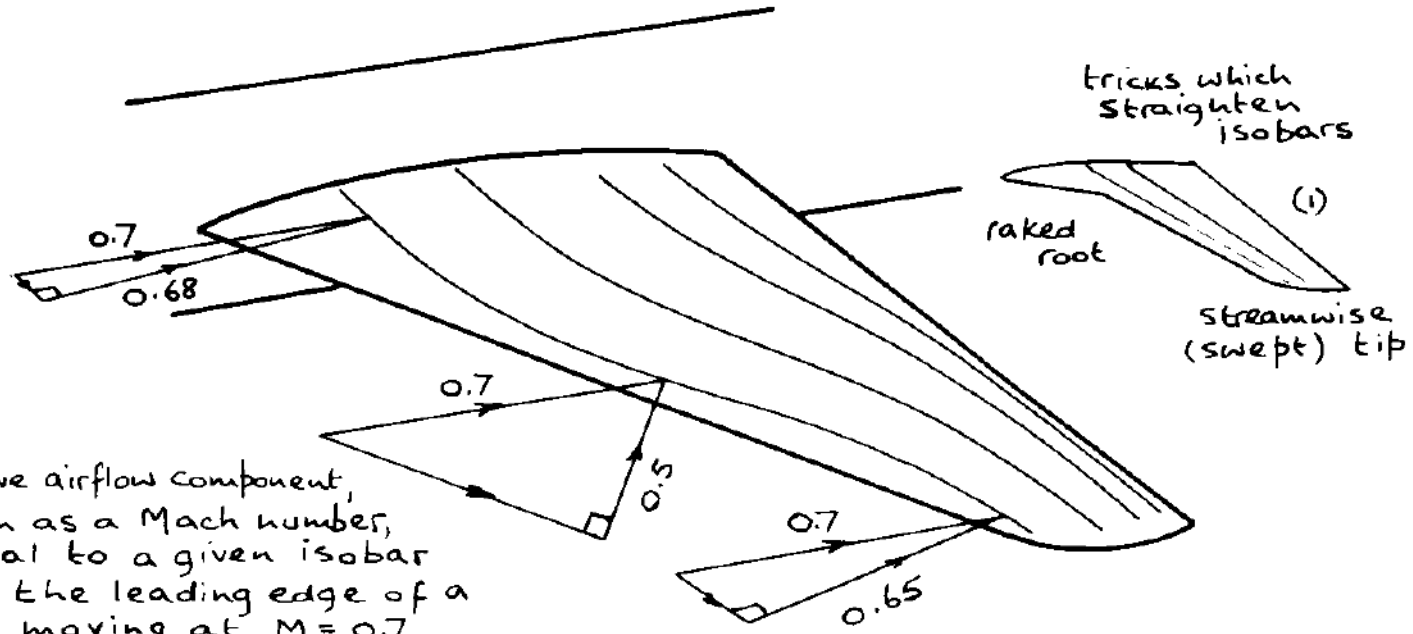
a. The aerodynamic chord of a wing may be extended and the section fined geometrically by sweep. The line of maximum thickness lies along the spar-line S.



b. Swept and delta wings with the same area and section, showing the greater volume of the delta.

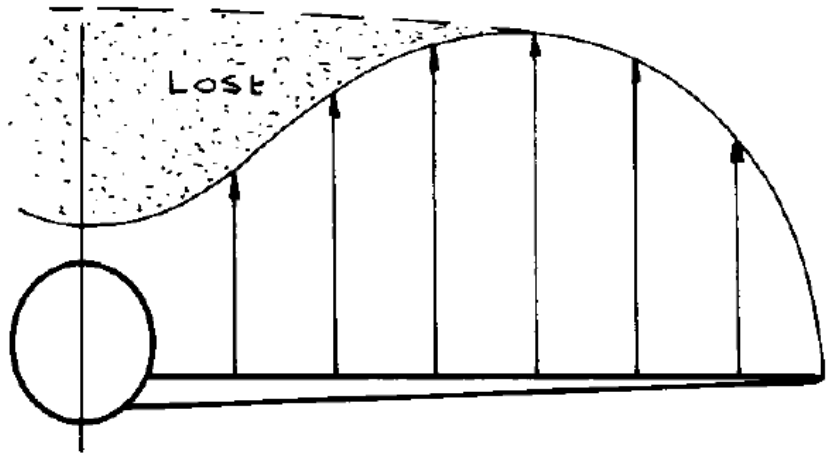


Ali finite, effetto della freccia



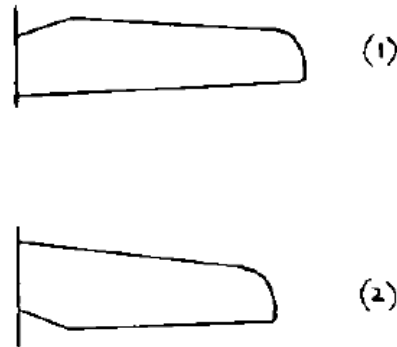
a. Relative airflow component, shown as a Mach number, normal to a given isobar near the leading edge of a wing moving at $M = 0.7$

b Loss of lift in vicinity of a body can be gross if the wing-body junction is badly shaped.

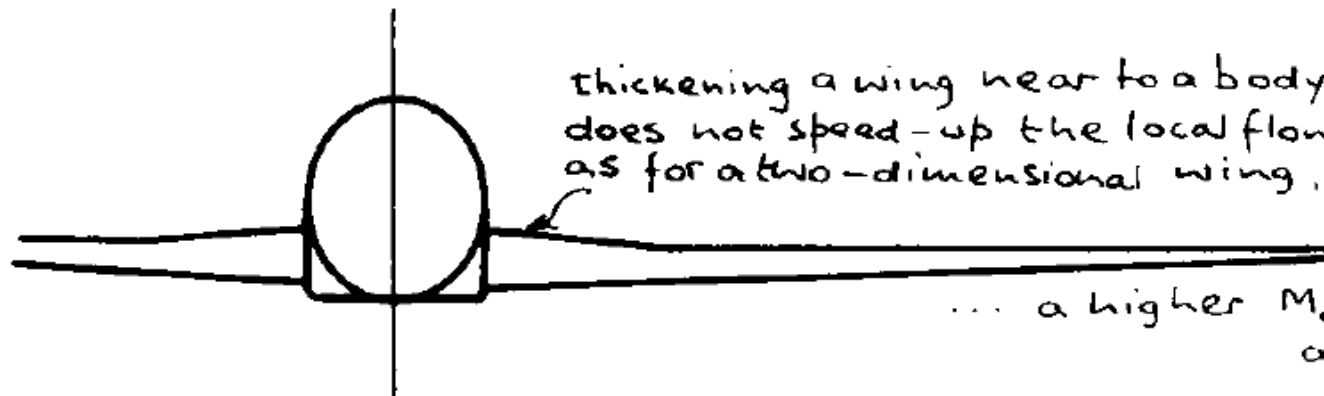


Ali finite, soluzioni locali

c. If the wing root has enough structural strength a reduction of local chord at the root can be beneficial, diminishing interference and profile drag, while improving longitudinal stability through a reduction in downwash with local angle of attack, $d\epsilon/d\alpha$, Eq(5-25) et seq.



Such roots are usually associated with external bracing, eg, struts.

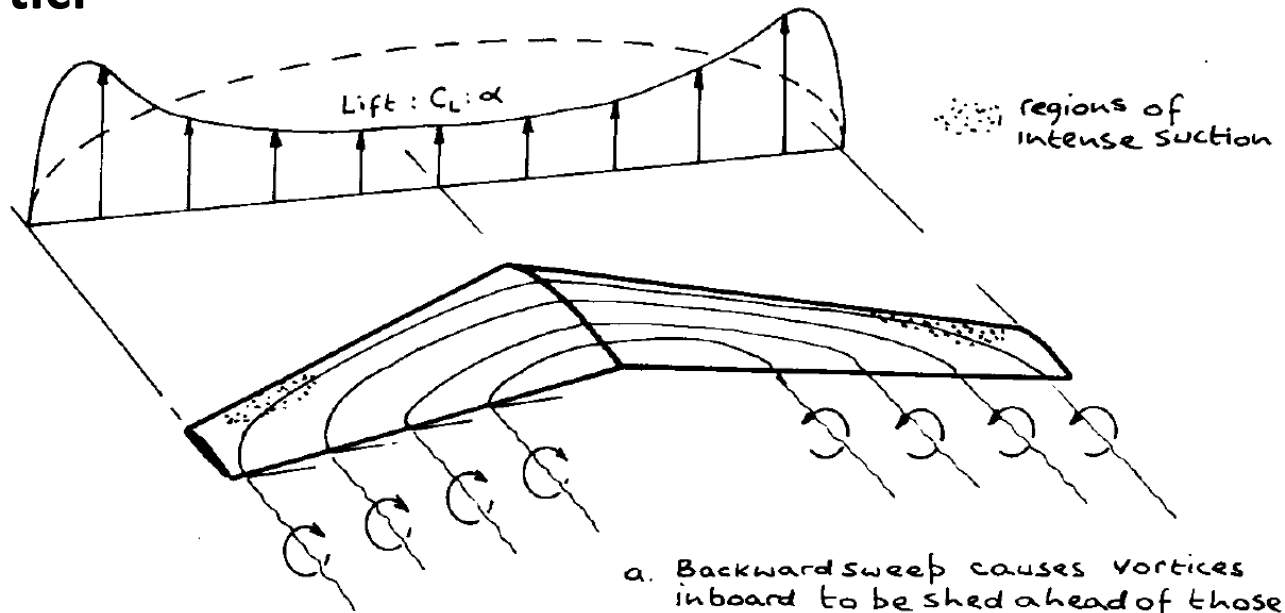


thickening a wing near to a body-junction does not speed-up the local flow as much as for a two-dimensional wing, therefore...

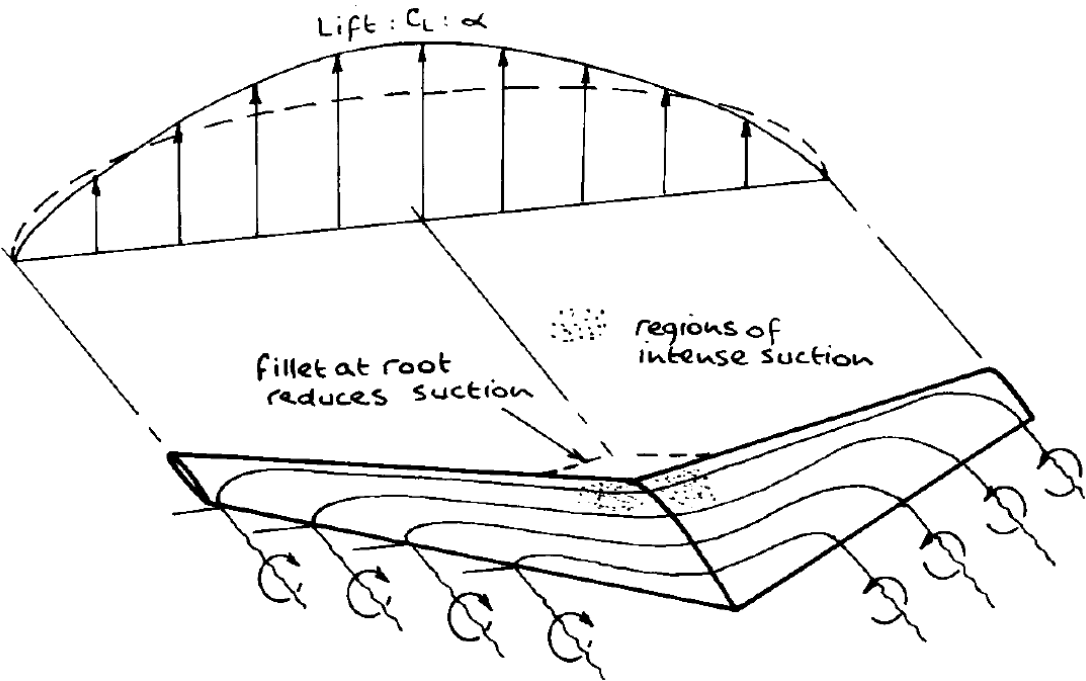
... a higher Merit can be achieved.

d. Thickened wing roots may be introduced without adverse effect upon Merit, so providing extra stowage volume (as on numerous modern airliners)

Ali finite, freccia e vortici



a. Backwardsweep causes vortices inboard to be shed ahead of those outboard, so inducing upwash towards the tips. Angle of attack and lift coefficient of outboard sections are increased, causing tips to stall first.



b. Forward sweep causes vortices outboard to be shed ahead of those inboard. The effect is the opposite of a: tip stalling is suppressed by off-loading outboard sections. The spanwise lift distribution of a forward-swept wing is nearly elliptic and further forward than for one swept back. This, with root losses, helps to shift the aerodynamic centre 7 percent to 10 percent further forward than for a sweptback wing.